GEOLOGICAL SURVEY OF CHINA.

中國地質史
STRATIGRAPHY OF CHINA

BY

A. W. GRABAU M. A., S. D.

CHIEF PALÆONTOLOGIST OF THE SURVEY AND

PROFESSOR OF PALÆONTOLOGY IN THE

NATIONAL UNIVERSITY, PEKING.

Part I

Palæozoic and Older

With Three Hundred and

Six Text-Figures and

Six Plates.

PEKING.

PUBLISHED BY THE GEOLOGICAL SURVEY

MINISTRY OF AGRICULTURE AND COMMERCE

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神仙傳:— 麻姑謂王方平曰接侍以來已見東海三爲桑田

Said Ma-Ko unto Wang-fan-pien: "Since I followed you I have three times seen the Eastern Sea become a land of mulberry trees".

Jenhsienchuan

Written by Kê-hung, 400, A. D.

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朱子語錄云:— 嘗見高山有螺蚌殼或生石中此石即舊日之土螺蚌即水中之物下者却變而爲高柔者却變而爲剛

"In high mountains there are shells. They probably occur in the rocks which are the soils of older days, and the shells once lived in the water. The low places became high, and the soft mud turned into hard rock."

Chutzeyülo.

Written by Chu-hsi, 1200 A. D.

Pages 1-200 inclusive, issued December 1923.
Pages 201-260 ,, ,, March 1924.
Pages 261-420 ,, ,, September 1924.
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The Commercial Press Works, Peking.

PREFACE

This work was originally intended to be one of the guide books of the Museum of the Chinese Geological Survey. There is in this Museum a stratigraphical section where each period of the Geological History is represented by specimens of rocks and fossils accompanied by descriptions both in Chinese and English and by illustrations. These descriptions and illustrations were prepared by different members of the Survey, each treating the part best known to him, with the larger number by Dr. Grabau who is in charge of palæontolgical researches. When entrusted with the task of putting together these descriptions with necessary revision in the shape of a guide book, Dr. Grabau found that since these descriptions were written in 1921-1922, new material was so fast accumulated, especially by the recent expeditions of the Survey, that many additions and expansions were necessary in order to give a complete idea of Chinese stratigraphy.

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On the other hand Dr. Grabau's studies on the palæogeography of Asia have made such progress and are of such high scientific interest that the Survey decided to publish them at an early opportunity. These studies are of course closely connected with the stratigraphy of China and can be conveniently published together.

Again experience has proved it desirable, and even necessary, to supply to the geologists working in the field some general summary of the geology of Asia in large, and of this country in particular, showing them what has been done and thence what is to be done. Illustrations of typical sections and index fossils of the different formations were also thought useful to those geologists who are pursuing extensive field work and who have not much time to devote to literary research.

It is the combination of all these schemes which results in the publication of the present work. This is mentioned in order to explain some of its features which may seem peculiar otherwise. Thus a few

paragraphs are directly taken from the Museum descriptions written by others, as J. G. Andersson, V. K. Ting, etc. which the author carefully acknowledges in the respective foot notes.

As it now stands this work is not only important because of the large amount of literary references it contains but also as a record of many new facts recently observed by the Survey geologists and palæontologists and published here for the first time. In fact the publication of the detailed reports by the field geologists is much behind the recent progress of their work. But isolated facts acquire their full significance only when they are gathered together into a general review such as the present work of Dr. Grabau constitutes. The palæogeographic maps and other stratigraphic interpretations based on such new observations, as well as a thorough digestion of geological literature of Asia such as has never been done before, will constitute, it is believed, important additions to the Science of the Earth. It is in this hope, to contribute to the advancement of our great science and to help all workers on the geology of this country, that the present work is edited by the Chinese Geological Survey.

V. K. Ting, W. H. Wong.

Directors

AUTHOR'S PREFACE.

This book is primarily written for the advanced student and the workers in Chinese geology, with the intent of summarizing what has so far been accomplished in stratigraphic exploration in China and in the adjoining Asiatic regions, and to make this knowledge serviceable as a foundation from which further studies may be carried on intelligently.

The student of Chinese geology can not ignore what has been done in other parts of the Asiatic continent, but the results of such studies are too often buried in scattered literature and under a multitude of foreign tongues. The average student has not the means to refer to the literature or even to know where to find this, except by long continued browsing through a well-equipped library. To furnish a guide to the literature then becomes no less imperative than to briefly summarize the essentials of this literature, so that the student may be enabled to choose intelligently that which will serve his needs. For this reason the aim has been to make the bibliographies at the end of each chapter as complete as possible, including all that seemed important in the literature on Asia, and as much of European and American literature as has a more or less direct bearing on Asiatic geology. I am well aware that my attempts in this direction are only partly successful. Situated as we are, far from the great library centers of the western world, with a library which, though growing daily in equipment and usefulness, still lacks much of the important older literature, it is not to be expected that all, even of the more important works can be listed, much less consulted and utilized in the development of this survey of Asiatic stratigraphy. But with the aid of our colleagues in all lands, and the recognition by governments, institutions of learning and men of science, as well as men of affairs, in all parts of the world, of the earnestness which animates Chinese scholars, and the indomitable spirit with which they undertake the solution of the problems of earth science in their own country, we are confident that vast gaps in the library will

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gradually be filled, and that in the not too distant future, this part of the world will become a great library center as it will become a center of scientific research.

Meanwhile the Survey will issue from time to time supplements to the present volume as well as to the second part, incorporating not only the new discoveries and interpretations in Chinese geology, but also bringing the bibliographic references up-to-date and including such works as had previously been omitted.

In the preparation of a work of this kind much aid is obtained from the general works of reference in existence. And here I wish to note first of all that indispensable reference work for all students of stratigraphy, the *Traité de Géologie* by Emile Haug, especially the second volume: *Les Périodes Géologiques*. More than ever before, I have realized the wide scholarship and breadth of knowledge of this, my valued French colleague, and I take this opportunity of expressing my admiration for his profound learning and his patience in bringing together the essentials of detail for all the countries of the earth. The extensive bibliographies in his volumes are an aid which only the special student can fully appreciate, and for nearly all literature other than that pertaining to Asia, the student is referred to this work. The Palæozoic volume of the *Lethæa* by Frech, though of immense value, is more difficult for students to use, because of the rather unsystematic treatment of the subject, but the Triassic volume, the only other so far completed, is a model of what such works should be, and is indispensable to the student and worker. The various numbers of the "Handbuch der Regionalen Geologie" dealing with Asiatic territory, contain of course the most complete and up-to-date summaries of the stratigraphy of the regions concerned, and should serve for constant reference. Suess' "The Face of the Earth" too, though very difficult to use, because of the scattering of the stratigraphic facts among discussions of structure and physiography, is a work of the highest importance.

Of the publications by government surveys and scientific institutions in Asia, those of the Indian Geological Survey should first of all be

mentioned, as they are beyond compare the works of prime necessity to the student of Asiatic, and more especially Chinese stratigraphy, bordering as they do on, and even entering into, Chinese territory on the south. The great monographs of Mansuy and his colleagues describing the fossils of Indo-China, and the more recent work of the Geological Survey of Indo-China correcting the mistakes, and extending the work of the older Survey, need only be seen to be appreciated. One might wish that the descriptions of fossils were less scattered, that the fascicles, as issued, would confine themselves to one horizon or one locality or to one class of organisms, which would greatly facilitate their use by the student. But of their intrinsic value and surpassing importance to the student of Chinese stratigraphy and palæontology, there can be no question.

The work of the Dutch and German geologists in the East Indies, and that of the French in Madagascar is of great importance, especially for the student of the younger formations. One might wish that for the purpose of making their work accessible to a wider circle of students the Dutch geologists had more generally employed the allied German tongue, forgetting in the wider patriotism of the scientist the more circumscribed patriotism of the members of a political unit. As it is, much valuable work is buried in a tongue which must forever be alien to the majority of scientific workers.

This complaint must be made with even greater vehemence against the Russians, whose work north of China, in Siberia and the Maritime Provinces, and on the west in Turkestan, etc. is of such intense significance to the student of Chinese geology. Yet it might almost as well be non-existent so far as its availability to the majority of geologists is concerned. Few geologists have the time, even if they have the ability, to acquire a reading knowledge of Russian, and there is no hope whatsoever that conditions will change in this respect in the future. For the sake of making their truly important scientific work available to the world, for the honor and prestige of their own country, Russian geologists should insist that they be permitted to publish their

official reports and their important scientific contributions in one of the three recognized languages of science, namely, English, German or French. At least the summaries in one of these languages should be more extensive, and should never be lacking as they are so frequently in the modern publications of the various Russian surveys.

The practice of the Chinese Geological Survey of publishing the main body of a paper, which is of more than local importance, in English, French or German, and of giving only a summary in Chinese, is to be recommended to our confrères, both on the north and on the south-east.

The importance of making their work available to the outside world has been fully recognized by the Japanese, who print all of their important articles in English or one of the other of the three recognized languages of science, issuing in Japanese only such publications as are of purely local significance. In consequence it has been possible to utilize the Japanese literature to the fullest extent, and to give full recognition to the light which the Japanese researches have thrown on the geological history of the continent.

When we now turn to China proper, we recognize of course the fundamental debt which the Chinese geologist owes to the great pioneers in the scientific exploration of this country. That many of the Chinese in ancient times have contributed observations and deductions of value, is being more and more recognised as modern scholars call attention to these earlier works. But the stratigraphic and palæontological research in this country began with the work of Pumpelly, and especially the epoch-making journeys of Ferdinand Freiherr von Richthofen. Few who have not been forced to study in detail these ponderous volumes of the record of von Richthofen's explorations, can fully appreciate their significance or realize the acumen, patience and energy of the author-explorer who, working under the tremendous difficulties which confronted an explorer in these earlier days, yet achieved such success in laying the foundations of Chinese geology.

The two volumes on the Palæontology (IV and V) which complete this series, and which were the joint labor of Dames, Lindström, Kayser, Schwager, Schenk and Frech, are of course fundamental. To the student of the invertebrate fossils of China the masterly work of Emanuel Kayser will serve as a model of what palæontological description should be. There have of course been many others who have contributed to this field, and their work is mentioned in the text and bibliography, but to the venerable German palæontologist, Professor Kayser, students of Chinese invertebrates especially delight to do honor. The work of Schlosser on the fossil vertebrates of China should also be noted, as laying the foundation of Vertebrate Palæontology in this country.

Next to the work of von Richthofen, that of von Loczy and his collaborators on the results of the journey of the Hungarian explorer, Count Bela Szechenyi, must be named among the classics of Chinese geological literature. Covering, as they do, much territory not visited by von Richthofen, they form an excellent supplement to the work of the earlier explorer.

Following next in order is the work of the Carnegie Expedition carried on by the geologists Bailey Willis and Elliot Blackwelder and the topographer R.H. Sargent. In this work American methods of detailed mapping, and investigation of limited areas were applied, and for the territory covered they serve as models of their kind. Indeed the careful stratigraphic work of Blackwelder and the palæontological work of Walcott, Weller, Girty and David White have carried our understanding of Chinese stratigraphy and palæontology a long step in advance. If detailed study tends to modify the stratigraphic conclusions, or add to the fuller understanding of the stratigraphic succession, this in nowise detracts from the importance of the work of these men, who with Pumpelly, Richthofen and Loczy were the pioneers in the scientific exploration of this country. Attention should also be called to the importance for China of the work of the Third Asiatic Expedition of the American Museum of Natural History in Mongolia, whose explor-

ations, now carried out on an unprecedented scale, will in a few years accomplish what would otherwise require many decades of exploration.

The Bulletins, Memoirs and maps published by the Chinese Geological Survey are, of course, indispensable to the student of Chinese geology, containing a wealth of detailed information. In addition to those already published, others are in course of preparation and will appear as fast as publishing facilities permit. The various fascicles of the Palæontologia Sinica published and in course of preparation will give a complete account of Chinese fossils. They appear in four series: Series A, Fossil Plants; Series B, Fossil Invertebrates; Series C, Fossil Vertebrates; Series D, Ancient Man. They and the other publications may be obtained from the Survey librarian, 9 Ping-Ma-Sze, Peking. Important shorter papers appear in the Bulletin of the Geological Society of China, obtainable at the same address.

One feature of this book may be thought to need explanation more than any other, namely the palæogeographic maps. No doubt there will be many who will regard the attempt to depict the ancient geography of Asia at this stage of our knowledge as highly premature. Premature it would be if the attempt were made to present with any degree of finality the details of this geography, but for the mapping of the larger units there is a wealth of facts. The existence of the Angara Land of Suess on the north since mid-Palæozoic time, has long been recognised, as has also the existence of the Indian land-mass, which has commonly been made a part of an extensive continent: the Gondwana-Land, though in my opinion much of this landmass is purely hypothetic. Tibetia is a positive land-mass first recognized, as such, by Bailey Willis, while Cathaysia and Gobia are elements for the first time delimited by the present studies. The existence of these land-masses, and of the major geosynclines, may be considered as demonstrated, though no doubt much modification of detail will be required with the advance of our knowledge. It may be mentioned in passing, that the Mongolian geosyncline in Dinantian and Permian times was outlined upon the maps purely because of the requirements of

palæogeography, and without positive knowledge of the existence of marine strata of this age in the region included in the geosyncline. Subsequent discovery, by the Third Asiatic Expedition, of both Dinantian and Permian strata with rich marine faunas, in the very heart of the region thus outlined, demonstrated the soundness of the principles on which the construction of these maps are based.

Although the entire work has been ready for some time, the slowness of printing (which began over a year ago) has decided the Survey authorities to issue this work in two parts. The printing of the second part will begin as soon as the first is issued. Already the progress of discovery, during the past year, has been such as to make necessary the addition of a supplementary chapter to the Palæozoic. While the delay in the issuance of the second part is deplored, because of its unavailableness to the student, this delay is not without compensation, for it makes possible the inclusion of the most recent investigations in Mesozoic and younger stratigraphy.

A work of this kind can not be brought together in a limited time without the aid of many colleagues and helpers. To mention all would be to give a list of the Survey members from the Directors to the youngest assistant, and of all the members of the Third Asiatic Expedition as well. A few must, however, be referred to in person. First of all I must record the unfailing encouragement and interest of the honorary director of the Survey, Dr. V.K. Ting, and of the active director, Dr. W.H. Wong. The former aided the work especially by his keen criticisms, and the latter by his sympathy, keen understanding of the requirements of such a work, and willingness to carry it on as far as conditions permitted and to illustrate it as fully as possible. It was Dr. Wong who conceived the idea of expanding what originally was intended merely as a small museum guide, into an illustrated handbook for the use of students and workers in Chinese geology. Dr. J.G. Andersson, mining advisor to the Chinese Government and director of the Survey museum, not only aided in the formulation of the plans for the book, but himself contributed a number of articles to various

chapters, both in part I and part II, as acknowledged in the text. For free permission to make use of his researches, particularly in the Cenozoic and Psychozoic geology of China, I am also deeply indebted to Dr. Andersson, as well as for the constant and friendly criticism and advice during the years we have been fellow students of Chinese stratigraphy and associates on the Survey. To Dr. H.T. Chang I am indebted for the quotations from the Chinese Classics. The work of many of the younger men on the Survey is mentioned in the text, and their unpublished researches have been made full use of in this work. Their readiness to furnish new facts and materials discovered by them is a fine illustration of the liberal scientific spirit which animates the entire Survey staff. I also wish to refer to the help given me by successive editors of the publication during its progress, Messrs. Yuan, Yih, Chow and Chu, and to the library staff of the Survey. While deferring credit for the contributions of the geologists to the text, I cannot forbear to mention here by name my young colleagues and assistants in the palæontological division, Messrs. Sun, Chao and Tien who were throughout most helpful. Our very able artist, Mr. K.C. Liu, who drew practically all the illustrations for this work, must also not be overlooked in this connection. My colleagues at the National University, especially Prof. J.S. Lee, and Prof. G.B. Barbour of Yenching University, have also been most helpful, as have also been many members of the Third Asiatic Expedition, especially Dr. Roy Chapman Andrews, the leader, Dr. Walter Granger, the palæontologist and Drs. C.P. Berkey and Fred K. Morris, the geologists. With my friend Dr. F. K. Morris, I have had many stimulating discussions of the problems herein considered. From the chief of this expedition, the leader in palæontological research in America, Prof. Henry Fairfield Osborn, I obtained much suggestive help in our discussions during his all too brief sojourn in Peking.

Finally, I must mention the more immediate assistance which I have received in preparing this volume for, and seeing it through the press. To my friend, Col. Milos Hess, formerly of Peking, I am much

indebted for substantial help with the Russian literature. To Mrs. F.K. Morris I am greatly indebted for comparing typewritten chapters with the original manuscript. But the most constant and sympathetic aid I have received from my able secretary Miss R.E. Burer, who not only took down from dictation many of the later chapters as well as additions to the earlier ones, a task requiring special study and preparation, but also rendered invaluable aid in the compiling and arranging of the bibliographies. Finally she has several times carefully read the proof, thus relieving me of much irksome labor.

In conclusion I venture to express the hope that this book may lead many of the foreign as well as native residents of all parts of China to examine the rocks of their own locality, and if they are fossilifreous, to make extensive collections, noting the precise occurrences of the fossils in the rock-profile, and to send these fossils to the Survey for study and description. In this way they will contribute in no small way to the advancement of our knowledge of the Stratigraphy and Palæontology of China.

Peking, July 20th, 1924.

CONTENTS OF PART I.

Preface - By V. K. Ting and W. H. Wong..... p. iii

Author's Preface..... p. v

Table of Contents of Part I..... p. xv

Introduction..... p. 1

CHAPTER I.

The Oldest Rocks of China..... p. 8

The Taishan Complex (Archæozoic or Archæan) (Contributed by J. G. Andersson) p. 10.—The Wutai System (Proterozoic or Wutaian) (Contributed by J. G. Andersson) p. 11.—Bibliography I, p. 13.

CHAPTER II.

The Sinian System..... p. 14

The Sinian System in the Hsuan-Lung area (Contributed by J. G. Andersson) p. 18.—The Nant'ou Tillite (Contributed by J. G. Andersson) p. 19.—Bibliography II, p. 21.

CHAPTER III.

The Cambrian System..... p. 22

The Lower Cambrian p. 22.—Middle and Upper Cambrian p. 26.—The Cambrian of South China and Indo-China p. 29.—The Cambrian of North China. p. 32. (The Lower Cambrian p. 33.—Middle Cambrian p. 34.—Upper Cambrian p. 36).—Bibliography III, p. 39.

CHAPTER IV.

The Ordovician System..... p. 42

General Characters of the Ordovician p. 42.—Faunal Provinces p. 47.—The Atlantic Province p. 47—(British Subdivisions p. 47.—British Ordovician Graptolite Zones p. 48.—Swedish Subdivisions p. 49.—Bohemian Subdivisions p. 50).—Ordovician of the Northern Shan States of Burma p. 52.—The Boreal Province p. 55 (North East American Subdivisions p. 57).—The Pacific Province p. 63.—Ordovician formations of North China p. 66.—Ordovician formations of South and Central China p. 81 (Yunnan p. 81.—Indo China p. 88.—The Tsingling Geosyncline p. 89).—The Kisingling limestone p. 91.—The Neichiashan formation p. 93.—The Lunshan Limestone p. 96.—Bibliography IV, p. 98.

CHAPTER V.

The Silurian System..... p. 103

General Characters and Subdivisions p. 103. (North American Subdivisions of the Silurian p. 110.—Classification of Silurian Rocks of West Europe p. 113.—Graptolite Zones of the Silurian p. 114).—Silurian of Asia p. 116 (Siberia, etc. p. 116.—Himalayas p. 117.—Burma p. 118).—Silurian of South China p. 123 (Western Yunnan p. 123.—Eastern Yunnan p. 125.—Tonking p. 127).—Silurian of Central China p. 129. (Nanking Hills p. 129.—Hupeh p. 130.—Tsingling Region p. 130).—Summary of Silurian of China p. 132.—Bibliography V, p. 136.

CHAPTER VI.

The Devonian System..... p. 140

History and Subdivisions p. 140.—Characteristics and distribution of the Devonian Formations p. 142.—Lower Devonian p. 142. (Lower Devonian of Central Asia p. 147.—Lower Devonian of the Altai region p. 149.—Lower Devonian of the Atlantic province p. 150).—Middle Devonian p. 151. (Ulsterian or Eifelian Epoch p. 151.—Erian or Givetian Epoch p. 158.) Upper Devonian p. 164 (Senecan or Frasnian Epoch p. 164.—Chautauquan or Famennian Epoch p. 172).—Upper Devonian of Asia p. 179 (Asia Minor p. 179.—Persia p. 179.—Afghanistan and the Western Himalayas p. 179.—Turkestan and the Tianshan Range p. 181.—Kirghiz Steppes p. 182.).—Early Upper Devonian from the Pamirs p. 183.—The Wetwin Shales of Burma p. 184.—The Devonian of China p. 187.—Middle Devonian or Yunnanian p. 188 (The Lower Series p. 188.—The Poshi Group p. 189.—The Kütsing Group p. 191.).—Upper Devonian or Tsinglingian p. 193. (Tahiti Formation p. 193.—Hanchung Formation p. 193).—Devonian of Indo-China p. 196.—Bibliography VI, p. 198.

CHAPTER VII.

The Dinantian or Mississippian System..... p. 208

General Geographic Relationship p. 208.—General Characters and Development p. 209.—Subdivision of the European Dinantian p. 213.—Table of the Dinantian of the Donetz Basin p. 218.—Dinantian of Asia p. 221 (Eur-Asian Border p. 221.—Persia p. 224.—Turkestan p. 225.—Kwenlun and Tianshan p. 225.—Sinkiang p. 226.—Siberia p. 233.—Mongolia p. 234.—Japan p. 235.—Himalaya Geosyncline p. 235).—Dinantian of the Chinese Basin p. 236.—Dinantian of South China and Indo-China p. 243 (Yunnan p. 243.—Indo-

China p. 247.—Szechuan p. 249).—Dinantian of Central China p. 249 (Nanking Hills p. 249.—The Yangtze Gorges p. 251.—Tsingling Geosyncline p. 251.—West Kansu p. 252).—The Taiyuan Series of North China p. 253 (Kansu p. 255.—West Shansi p. 255.—Central Shansi p. 255.—Chihli p. 256.—Shantung p. 256).—Continental Beds and Coals of the Taiyuan Series p. 257.—Bibliography VII, p. 258.

CHAPTER VIII.

The Higher Carboniferous Formations..... p. 264

The Younger Carboniferous Formations of Europe p. 264.—Marine Divisions of the Younger Carboniferous p. 264.—Non Marine Divisions of the Younger Carboniferous p. 268.—The Younger Carboniferous Formations of Asia p. 271. (Asia Minor p. 272.—Syria and Arabia p. 273.—Persia p. 274.—Turkestan p. 275.—The Tianshan Ranges of Western Sinkiang Province p. 278.—Siberia p. 286.—Himalayas p. 287). Moscovian Time in China p. 292.—Late Lower or early Middle Carboniferous (Culm) in the Indian Ocean Region p. 293.—Uralian Deposits in China p. 295.—Southern China p. 295.—Central China p. 297. (Nanking Hills p. 297.—Yangtze Gorges p. 298).—Indo-China, etc. p. 299.—Geographic Development in Later Carboniferous Time p. 301.—Bibliography VIII, p. 308.

CHAPTER IX.

The Permian System..... p. 317

The North European Basins p. 317.—The Southern European Basin p. 322.—The Permian System in Asia p. 327.—The Standard Section p. 327.—Table of the Upper Palæozoic Beds of the Salt Range p. 328 (The Glacial Tillites p. 329.—The Speckled Sandstone or Pendschab Series p. 333.—The Lower Productus Limestone p. 333.—The Middle Productus Limestone p. 334 —The Upper Productus Limestone p. 336).—The Permian Elsewhere in Western and Central Asia p. 336 (Asia Minor p. 336.—Djulfa Section and Persia p. 337.—Turkestan and Sinkiang p. 338.—Siberia and Mongolia p. 339.—Himalaya Geosyncline p. 340.—Burma p. 348).—Marine Permo-Carboniferous and Permian in China and Adjoining Districts p. 351.—South China, Indo-China and the Borders of the Asiatic Continent p. 351. (East Yunnan p. 351.—Indo-China and Siam p. 352.—Malay Peninsula and East Indies p. 354.—Japan, etc. p. 358).—South-Eastern and Central China p. 360 (Hunan p. 360.—Kiangsi p. 360.—Southern Kiangsu and Northern Chekiang Provinces p. 364.—Summary p. 366.—Tsingling Geosyncline p. 366.—North-West Chinese Basin p. 370)—North China p. 371 (Shansi p.

371.—Chihli p. 379.—Flora of the Kaiping Basin p. 381.—Shantung p. 382.—Manchuria p. 383).—The Gigantopteris Flora p. 388.—Supra-Carboniferous Continental Formations p. 393 (China p. 393.—Lower Angara Beds of Siberia and Mongolia p. 394).—Tectonic Disturbances and Volcanism p. 408.—Bibliography IX, p. 409.

APPENDIX.

SUPPLEMENT A.

Additions to the Palæozoic Stratigraphy of China and Adjacent Regions ..... p. 421

Sinian System p. 421. (China p. 421.—India and the Himalayas p. 422).—Cambrian System p. 425 (General p. 425.—China p. 426).—Ordovician System p. 428.—Graptolite Shales p. 428 (New Zealand p. 428.—China p. 428).—Lower Ordovician Limestone p. 433.—Higher Ordovician p. 435.—Silurian System p. 435.—The Wutung Quartzite p. 440.—Devonian System p. 442.—Dinantian System p. 443.—(Yangtze Valley p. 443.—North West Chīna, Kansu p. 447.—South West China, Yunnan p. 448.—Mongolian Geosyncline p. 453).—Palæogeography of China in Dinantian time p. 453.—The Taiyuan Series p. 455. (North China p. 455.—South West China, Yunnan p. 464).—Palæogeography of China in Taiyuan Time p. 466,—Extra Chinese Territory p. 467.—Permian System p. 468.— Central and South East China p. 468. South West China, Yunnan p. 488.—North China p. 491.—Summary of Permian Palæogeography p. 498.—Supplementary Bibliography A. p. 505.

Alphabetical List of Chinese Geological Formation Names (Palæozoic and Older), with Revised Spelling, and Chinese Characters ..... p. 513

Errata ..... p. 521

Explanation of Plates ..... p. 523

PLATES

Plate I. Palæogeographic Map of China in Viséen Time.

Plate II. Palæogeographic Map of China in Taiyuan Time.

Plate III. Palæogeographic Map of China in Lower Permian Time.

Plate IV. Palæogeographic Map of China in Middle Permian Time.

Plate V. Palæozoic Sections of the Yangtze Valley Region.

Plate VI. Correlation table of the Palæozoic Formations of China.

STRATIGRAPHY OF CHINA.

BY A. W. GRABAU.

INTRODUCTION.

GEOLOGY is the science of the earth on which we live. As the framework of the earth is made of rock, the geologist must begin his studies with the rocks; he must observe their composition, he must learn to distinguish between the different types, which for convenience he designates by special names, and he must determine the history or mode of origin of these rocks, and their significance in the architectural plan of the earth as a whole. But this is not all of geology, it is only a part, though a very fundamental part, of the science. It is the division called petrology. Armed with the knowledge of the nature and origin of rocks, and of their structural relations, the petrologist can search for, and discover, the mineral deposits which are segregated in favored portions of the earth's crust, and find and make available the natural resources upon which the material prosperity of the peoples of the earth depends.

But it would be a mistake to believe that geology caters only, or even primarily, to the development of material wealth. Geology has a much greater service than that to perform for humanity. The supreme task of the geologist is the discovery of truth—it is for him to ascertain the true history of the origin and development of this earth, to discover the forces and conditions which have guided the development of life upon it, and to find the causes which have forced the living organisms into ever widening realms of activity, and demanded constantly increasing powers of adaptation to a changing environment as the price of continuity of existence.

The geologist is not a theorist, he is an interpreter of facts. His interpretations may be incomplete or faulty—they are certain to be so, if his facts are limited, but he improves and corrects them by the

unremitting and relentless search after new facts If he demolishes age-old structures, reared by superstition, fostered by ignorance, he does so, not in the spirit of vandalism, but because he has learned by painful labor that they rest upon an insecure foundation. Iconoclast he must ever be, but he is always ready to demolish his own temporary structures when he becomes convinced of their inadequacy for the housing of the growing body of facts.

The geologist who confines himself to a limited area, may contribute important facts to the body of knowledge, but his interpretations are apt to be at fault. The geological history of China can not be rightly interpreted by the student who confines himself to a study of the Chinese rocks and fossils. These, of course, must be investigated in the greatest detail, and the results of these investigations must be recorded in permanent form, for the use of future generations. For the span of life of no man is sufficient for the rearing of the entire edifice, each can at best build only a small section of the temple of truth, and trust to his successors to continue where he left the work. If that work has been conscientious, and if it will stand the test of future discoveries, it will remain a part of the growing structure. If not, it must be demolished, and building must commence anew.

But if interpretation of facts is to have a lasting value, that interpretation must be made in the light of all the available knowledge. China is a part of Asia, and the history of China can only be correctly interpreted in the light of the history of that continent. But the history of Asia is a part of the history of the earth, and interpretation of the geological history of Asia without reference to the geological history of the rest of the earth is impossible. So the circles widen, and the pebble of fact, dropped into the sea of knowledge at any point, will send its ripples to the remotest shores, and though the ripple may be but a tiny one, its effect at any given point, can not be calculated beforehand.

The facts with which the geologist deals are for the most part unfamiliar to the average man, and the terms by which they are expressed are not a part of his usual vocabulary. But new ideas and new facts demand new terms in which to clothe them, and the seeker after knowledge must not be discouraged by the necessity of learning new words and phrases. The language of the geologist is not difficult to learn, and may be acquired from any elementary textbook on the subject. In point of fact, a knowledge of the periods of earth history should be a part of a well-rounded modern education, just as a knowledge of the periods of human history is commonly considered to be. So should be a knowledge of the common terms by which the classes of animals and plants are known. The names of genera and species form a more formidable obstacle, but after all, the number of those essential to a fair understanding of the subject is limited, and familiarity with them may be a matter of gradual acquisition, as acquaintance with the objects they represent increases. Familiarity with the objects themselves is far more important than a knowledge of their names, and this may be gained from a study of the illustrations, and from the objects themselves. This explains the reason for the numerous figures of these fossils in the text, and makes apparent the value of the museum exhibit to the student of earth history. It is by frequent visits to the museum of the Geological Survey and by a systematic study of its exhibits, that the non-geologically trained seeker after wider knowledge, can prepare himself for an understanding of the geological history of China, and an appreciation of its significance in the history of the development of our earth.

Within the territory of China are to be found representatives of almost all of the large rock systems now recognized elsewhere, but they are not equally developed. The Archæozoic and Proterozoic Eras are each represented by one rock system, these being the Archæan or Taishan complex, and the Wutaian (Wutai System) respectively.

Both consist of highly metamorphosed rocks, in part of igneous and in part of clastic origin. Wherever present, the rocks of the Palæozoic Era overlie these crystallines with a major unconformity, the younger rocks being little or not at all metamorphosed. In most areas the rocks of the several systems of the Palæozoic are concordantly related to one another, though separated by many disconformities, these occurring between, as well as within the system; but in a few cases there are actual unconformities between some of the systems, due to local folding during the Palæozoic.

The oldest of these unmetamorphosed sediments are here classed together in the Sinian System, this term being used as nearly as possible in the sense in which it was proposed by von Richthofen, not in the Bailey-Willis sense (see beyond). These Sinian rocks are placed by the author at the base of the Palæozoic, as its oldest known system, underlying the rocks of the Cambrian System. This is held to be their proper position in the geological classification, although in the past they have generally been classed as an upper division of the Proterozoic.*

Except this lowest one, all the systems of the Palæozoic are represented, at least partially, by marine members, though several of them, especially the later ones, are largely, and in some cases entirely, formed of continental members, in some sections of the country. Of the Mesozoic systems, only the Triassic and Jurassic are represented by marine members within the territory of China proper, though in Tibet and elsewhere in Asia the Cretaceous also includes marine sediments.

The Cenozoic and Psychozoic (Tertiary and Quaternary) Eras, are also represented primarily by non-marine sediments in China, though here again, marine facies are found in Tibet and elsewhere

*For discussion of this problem see: A. W. Grabau "The Sinian System" Bulletin of the Geological Society of China, Vol. 1. 1922.

in Asia. At present it is not possible to sharply draw the line between the Cenozoic and Psychozoic deposits, as Pliocene and Pleistocene sediments commonly intergrade, or at least are not separated by a recognizable division-line. Therefore it has been found more convenient to divide the post-Mesozoic deposits into an older, which is essentially the older Tertiary, and a younger series, which includes the younger Tertiary (Miocene and Pliocene) and the Quaternary deposits (Pleistocene and Holocene). The division-line is drawn between the Oligocene and the Miocene, where it is readily recognizable in the field. The older division is grouped as *Eogene* and the younger as *Neogene*, it being understood that in this latter division, as here used, the youngest of our sediments are included.

Thus modified, the table of Geological Systems for China is as follows:

NEOGENE SYSTEMS

Including Psychozoic or Quaternary, and younger Cenozoic (younger Tertiary).

Recent deposits (*Holocenic*)	Human culture deposits. Fluviatile deposits of south China; estuarine deposits.
Pleistocene	The Loess and associated deposits.
Pliocene	Cave deposits and *Hipparion* beds (in part).
Miocene	Hipparion beds (in part); Tectonic disturbances.

EOGENE SYSTEMS

(Older Tertiary)

Oligocene	Represented by plant-bearing beds.
Eocene	Beds with vertebrates, and fresh-water mollusks. Marine in Tibet.

Palæocene.....Not known to be represented.

MESOZOIC SYSTEMS

Cretacic.....Mostly continental, marine in Tibet.

Comanchic.....Chiefly beds of Wealden type.

Jurassic.....Some marine but mostly continental beds. The Upper and Lower unconformably related. Igneous flows and intrusions and tectonic disturbances in Middle Jurassic.

Triassic.....Marine beds in south China and Tibet; continental beds in central and north China.

PALÆOZOIC SYSTEMS

Permian.....Marine beds in south China; continental (mostly) in north China.

Carbonic.....Higher part (Uralian) represented by marine beds in south and central China. Moscovian mostly absent, except for local (provincial) development in Yunnan.

Dinantian.....Uppermost part or Taiyuan series, widely distributed; Visćen in central and south China; Older divisions absent.

Devonian.....Upper Devonian in central and south China; Middle Devonian in south China; Lower Devonian absent.

Silurian.....Upper Silurian in south China; Lower Silurian in central and south China; Middle Silurian absent.

Ordovician	Upper Ordovician absent. Late Middle Ordovician widespread; northern phase American; southern phase (central and southwest China) European. Older Middle Ordovician probably largely wanting. Lower Ordovician; northern phase American; southern phase (west-Yunnan) European.
Cambrian	Upper and Middle Cambrian in north China, (northern phase) extending into Tonking. Lower Cambrian best developed in south China (Yunnan) with extension northward to Manchuria etc.
*Sinian**	Represented by continental strata with algous limestones in north China, possibly also central China.

PROTEROZOIC SYSTEM

Wutaian	Wutai system of north China, strongly metamorphosed.

ARCHÆOZOIC SYSTEM

Archæan	Taishan complex of north China. Ancient crystallines of central and south China.

*Placed in the Palæozoic by the author.

CHAPTER I.

THE OLDEST ROCKS OF CHINA.

Underlying all of the rocks of China,—beneath the sands of the great plains, under the loess of the valley bottoms, and below the solidified conglomerates, sandstones, shales, and limestones, which form so large a part of the modern mountains of China, and of its plateaus and valley bottoms,—beneath all this mass of younger rocks, lies the ancient complex of crystalline formations, which forms the foundation of the continent and to which belong the oldest rocks of China. Antedating them all, in point of origin, by so vast a period of time that it is not measurable in years or centuries, this rock complex challenges our attention, and bids us pause to note the inadequacy of human chronology when applied to the history of the earth itself. From out of an antiquity so vast, that even the half hundred centuries of Chinese history sink into insignificance, these foundation rocks of China testify to the immensity of time which was consumed in the building of the Asiatic continent, and during which the plant and animal forms as we know them today, were slowly evolving.

Though underlying every part of China, these ancient rocks come to the surface only in relatively few localities. Foremost among these are the ancient land masses which have never been wholly submerged by the sea during any geological period. *Tibet* is one of these, and it is perhaps the most completely preserved of the permanent land masses, its ancient rocks being covered only by the still largely unconsolidated young sand, gravel, and loess deposits, or by Mesozoic deposits in part only of marine origin. To the east and southeast of the Chinese basin, are the remnants of the old land of *Cathaysia*, which included not only the eastern margin of the present Asiatic continent,

but also the islands lying east and south of it. Both Japan and the Philippines were a part of it at one time, as were also the East Indian islands. Though partly submerged in the late Palæozoic (Permian) and in the Mesozoic, the final dismemberment of Cathaysia did not take place until comparatively recent times, when by downfaulting and folding, portions of the land disappeared beneath the sea, leaving the present islands as remnants. On the continent, the granites, porphyries, and ancient crystallines of Kwantung, Fukien and Chekiang and those of Shantung and Korea form remnants of this ancient mass.

A third remnant of old land is found in Inner Mongolia, partly buried however by Tertiary sands and clays and by basalt flows. This constituted a part of the Palæozoic old-land of *Gobia* which separated the Chinese basin from the geosyncline of Outer Mongolia. In some places these ancient rocks have been peneplaned to a surprising level, permitting easy motor traffic across a thinly veneered or bare surface of erosion on granite and ancient metamorphic rocks.

Besides these ancient land masses, which were never wholly covered by the sea and only in part by deposits of continental origin, there are the ranges of ancient crystalline rocks which now appear upon the surface as the result of the erosion of the strata which once covered ahem. The Tsingling range is one of these, although the crystallines of this range were not covered until Carboniferous time, having been a source of supply for the strata accumulating in the Tsingling geosyncline, during early Palæozoic time. Another district in which the crystallines are exposed as the result of uplift and erosion, is the Wutai-shan of Shansi, while a number of other localities in both north and south China, also show these rocks. A fair understanding of the general characteristics of these rocks may be gained from the detailed consideration of typical examples.

The Taishan Complex—Archeozoic or Archæan*

The Archæan or Taishan complex is the oldest formation known in China and has its type locality in Taishan (Shantung). Nothing distinctly older has as yet been identified. It underlies all other recognized groups and is separated from them by an unconformity of a most distinct and profound character.

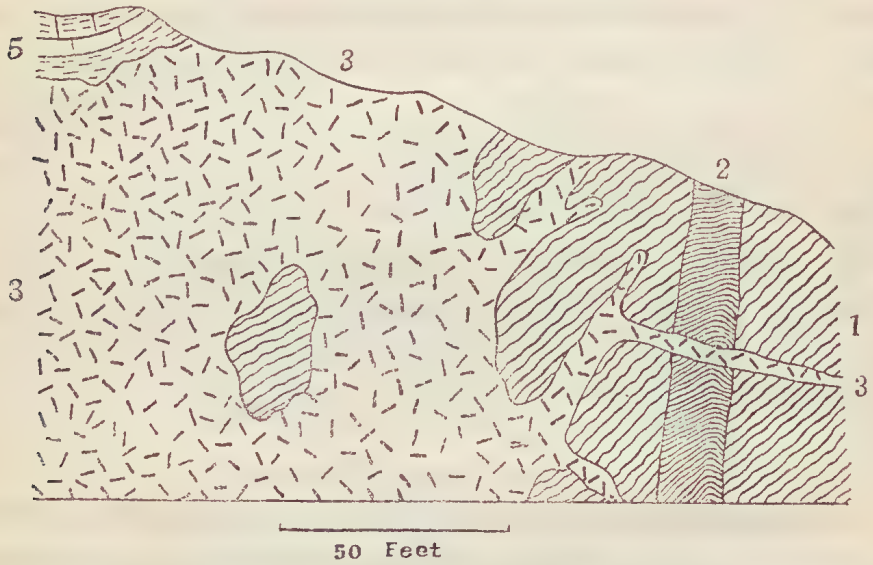

Fig. 1. Section of the Taishan complex at Chang-Hsia Hsien, Shantung (after Blackwelder). Ancient gneiss (1), intruded by schistose dike (2), and the two cut by massive red granite (3). The complex is unconformably overlain by Cambrian sediments (5).

The rocks of the Taishan complex are chiefly gneisses of indeterminate origin and character, and gneiss-granite; associated with them are metamorphic schists, such as mica schist, amphibolite etc. All the metamorphics are intruded by granite, which is relatively young, though in large part probably pre-Cambrian.

The structure of the gneisses and schists is exceedingly intricate; it is characterized by a universal schistosity, by a common

*Contributed by Dr. J. G. Andersson

banding, by complex shearing, thinning, thickening, plication and flow of bands.

Besides occurring in Shantung, the Taishan complex is also exposed in Fengtien, Kirin, Heilungkiang, Chihli, Shansi, Shensi, Kansu, Honan etc., all in northern China. In southern China gneisses and granites have been found in N.W. Szechuan, Hupeh, Anhui, Fukien, Kiangsi, Kwangtung, etc. and belong probably to the same formation.

Fig. 2. Detail of a small part of the Taishan complex of Chang-Hsia-Hsien, Shantung (after Blackwelder). Ancient gneiss (1), included in massive red granite (3), the whole crossed by veins of pegmatite (4).

In the Archæan gneiss gold ores are found in Heilungkiang, Kirin, Fengtien, Shantung etc. Iron-ores are also found in the Archæan gneiss and granite, as for example in Luan Hsien in N.E. Chihli. In S. Shensi and N.W. Hupeh, copper ores are known to occur in metamorphic rocks which may also belong to the Archæan. The sections (Figs. 1, 2) show the structure and relationships of the rocks of the Taishan complex.

The Wutai System—Proterozoic or Wutaian*

The Wutai System rests unconformably on the Taishan com-

*Contributed by Dr. J. G. Andersson.

plex and, like the corresponding Huronian of Lake Superior in the U.S.A., belongs to the Proterozoic Era. In its type locality, in Wutai

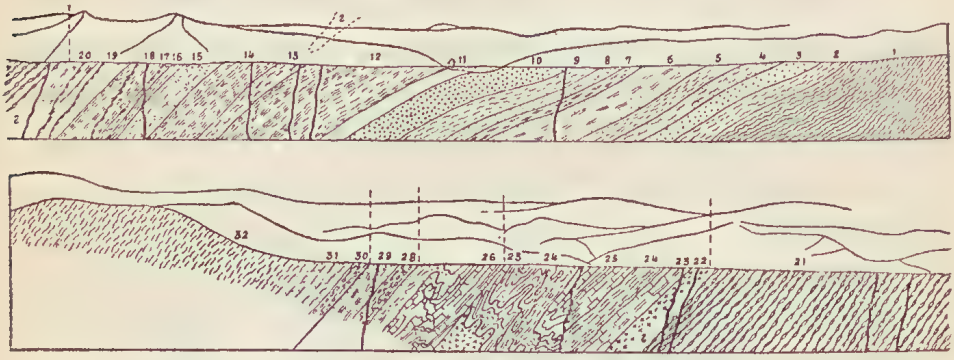

Fig. 3. Section of the Wutai system on the Tai-shan-ho from southeast to northwest across the southeastern slope of the Wu-t'ai-shan. (after Blackwelder).

1, Biotite-gneiss; 2, Biotite-schist; 3, Arkose-quartzite; 4, Micaceous quartzite; 5, Biotite-schist; 6, Micaceous quartzite; 7, Biotite-schist; 8, Micaceous quartzite; 9, Biotite-schist; 10, Quartzite; 11, Concealed by alluvium; 12, Mica-schist and gneiss; 13, Arkose-schist; 14, Muscovite-schist and gneiss; 15, Amphibolite; 16, Mica-schist; 17, Amphibolite; 18, Mica-schist and gneiss; 19, Magnetite-quartzite; 20, Quartzites with Mica-schist; 21, Augen-gneiss; 22, Biotite-schist; 23, Marble with layers of garnet-schist; 24, Chlorite and biotite schists; 25, Marble; 26, Siliceous marble with slate and hematite; 27, Quartzite; 28, Schistose conglomerate; 29, Quartz-mica-schist; 30, Schistose conglomerate; 31, Quartz-mica-schist; 32, Chlorite-schist.

Shan (Shansi), a provisional classification may be made as follows:

Wutai System	Unconformity
	Sitai Series. Chiefly chlorite schist and quartzite, with conglomerate at the base.
	Unconformity
	Nantai Series. Siliceous marble, jasper, quartzite and schist.
	Unconformity
	Shitsui Series. Mica schist, gneiss, magnetite quartzite, and basal feldspatic quartzite.
	Unconformity

The typical section of this system is shown in Fig. 3.

This system is well known in Shansi, but it occurs also in Shensi, Chihli and Jehol. Probably of the same age are the black quartzites, the hornblende-schists and the Takushan quartzites in Fengtien, Richthofen's Kingsunshan and Tschangshan Series in E. and W. Shantung and the crystalline schists and the crystalline limestones in Honan.

Minerals, containing magnesia, are found in abundance in this formation, such as dolomite and magnesite in S.W. Fengtien, talc and asbestos in Jehol, Shansi, Chihli, Fengtien etc. Graphite is also so be seen, but not in large quantities. Among the metallic ores, gold, tilver and lead are the most important. Copper-ores and iron-ores are also found, as for example in S.W. Shansi and S. Fengtien respectively. Zincblende, molybdenite and wolframite are also known to occur, sometimes in small quantities.

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CHAPTER II.

THE SINIAN SYSTEM.

The Sinian System was established by von Richthofen, who included in it all the unmetamorphosed sediments from the Cambrian downwards.* At present the term is restricted to the pre-Cambrian portion of this complex, that part which v. Richthofen called Lower Sinian. This is a vast series of ancient sediments which, so far as known, are wholly of continental origin, not only in China but in other parts of the world as well (*Belt terrane* etc. of North America, *Torridonian* of Europe etc.). They generally underlie the Cambrian beds with a disconformity (more rarely a moderate unconformity) and are separated from them by a hiatus of moderate magnitude. From the older rocks on the other hand, they are separated by a violent unconformity, and a hiatus of the first magnitude. They are readily distinguished from the older rocks, the *Wutai* and *Taishan* systems, by their essentially unmetamorphosed character, whereas the older systems, one or the other of which forms the basement on which the Sinian rocks were deposited, are highly metamorphosed.

The Sinian System of northeastern China was deposited in a geosyncline which, in general, extended in a northeasterly direction through the provinces of Shantung, Chihli and Shansi, being continued northeastward in Fêngtien, and for an unknown distance beyond. In general three belts may be recognized, each of which presents a distinct lithologic facies. The easternmost, exposed in Shantung and continued into eastern Fêngtien, is a sandstone facies, which has at present not

*Bailey Willis and E. Blackwelder have used the term Sinian as a synonym for Cambro-Ordovician, a usage which is inadmissible. See A. W. Grabau, The Sinian System, Bulletin Geological Society of China Vol. I, 1922.

been fully delimited, but apparently includes the Yungning sandstone of the Liaotung peninsula (Manchuria). A similar red sandstone occurs in southern Shansi and the adjacent part of Honan, where it is widespread and associated with diabase and porphyries, most of them however older than the sandstone. These sandstones appear to have been formed as a series of flood-plain and alluvial-fan deposits along the eastern border of the geosyncline, by streams coming from the western slopes of the mountains which bordered the geosyncline on the southeast and which formed a part of the continent of *Cathaysia*—the old-land of eastern China in Paleozoic time. As these sediments are today largely red in color, it would seem that the climate of this region was relatively dry in Sinian time, permitting thorough oxidation of the sands and muds, a process which could not have taken place if the climate had been moist enough to permit extensive growth of vegetation. But the evidence of the limestones in the region further westward indicates the existence there of bodies of water, and hence the semi-aridity of the eastern belt must have been due to a local cause. This cause seems to have been the height of the bounding ranges of mountains which supplied the sediments, and the fact that they intercepted the moisture-bearing winds from the southeast. If that was the case, the belt of easterly winds must have been shifted further northward at that time, than the position which it now holds.

The second belt of Sinian rocks, which occupies the center of the old geosyncline, constitutes the *Nankou group* first named by v. Richthofen from the Nankou mountains north of Peking. This series is largely calcareous, comprising the great Nankou limestone which in turn is overlain by the black Hsiamaling shales.

The NANKOU LIMESTONE forms the main rock of the Nankou range, and has a thickness of several thousand meters. It is in places a rather pure magnesian limestone, fairly thick-bedded, and contains an abundance of calcareous algæ, which appear to be the

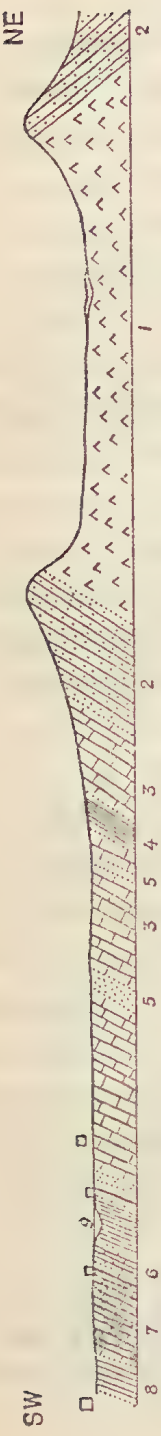

Fig. 4. Section of the rocks of the Sinian System on the northern margin of the Kaiping Coal Basin, east Chihli (J. G. Andersson).
1, Archæan mica-schist and granite; 2 to 5, *Sinian System* (2 Quartzite sandstone; 3, cherty limestone; 4, red shale; 5, sandstone). 6, *Cambrian*. 7, *Ordovician* limestones. 8, *Carboniferous* (Taiyuan and Shansi Series). 9, Alluvium.

chief if not the sole source of the lime and magnesium carbonate. Three species of these fossil organisms have so far been recognized, all being provisionally referred to the genus *Collenia*. These are:

3. *Collenia angulata* Grabau
2. *Collenia sinensis* Grabau
1. *Collenia cylindrica* Grabau

So far as determined, these species occupy successive horizons, no. 1 being the lowest. They are common in the exposures in Nankou pass, but have also been noted elsewhere in this limestone in north China. Excellent examples of these fossil algæ may be seen in the dark limestone blocks which form some of the steps leading to the hospital building of the Peking Union Medical College (Yüan Fu) especially those leading to the central building. They are also seen in the steps of the Anatomy building and elsewhere. These blocks came from a quarry at Fang Shan close to the Ching Han R. R. near Chowkoutien station.*

A large portion of the Nankou limestone is thin-bedded, and contains an abundance of chert. Hence it is often

*I am indebted to Doctors Houghton and Davidson Black for information regarding the origin of these blocks. Students should not neglect seeing them—as they are good examples of the most ancient organic remains found in China.

referred to as the *Siliceous limestone* under which name it is mapped in the Western Hills. Layers of ripple-marked sandstone and even fine conglomerates not infrequently alternate with these limestones in the lower part, indicating that they were deposited in shallow, probably temporary lakes, but whether these were fresh-water or saline lakes has not been determined. It is certain however that these waters were not marine. In the Nankou range the limestone is much intersected by igneous intrusions of later date. In western Chihli this limestone has been called the *Tayang limestone* by Bailey Willis.

The black Hsiamaling shales which overlie the Nankou limestones in some sections appear to be an extension of the western belt of sediments. They have not yet furnished fossils, but the remains of Eurypterids may be looked for in them. An intermediate section, showing the various members of the series, is well exposed in the rim of the Kaiping basin near Chao-kou-chuang (Fig. 4).

The westernmost belt of sediments of this system is largely a shale series, and was mapped by Bailey Willis under the name of Hut'o group. This is typically exposed in the Wutai Shan region of north-western Shansi, where Bailey Willis has made the following subdivisions:

Hut'o group	Tungyü limestone	900 m.+
	T'out'sun shales	1000-1800 m.

The T'OUT'SUN SHALES consist of red and gray quartzite with layers of conglomerate at the base (possibly an extension from the eastern belt) followed by gray to purplish shales or phyllites, with thin layers of dolomite and siliceous limestone.

The TUNGYÜ LIMESTONE is mostly gray, thin bedded, and contains chert in notable quantities, this often occurring in masses or sheets.

The following two phases of the Sinian system of rocks are of especial interest.

The Sinian System in the Hsuan-Lung Area.*

In northernmost Chihli, in Lung-Kuan and Hsuan-Hua-Hsien, there is a remarkable development of the Sinian system, characterized above all by the occurrence of very considerable deposits of bedded hematite ore.

With an unconformity of the first magnitude, the deeply decomposed Archæan gneiss is overlaid by the rocks of Sinian age. The lower part of this system consists mainly of quartzite sediments interbedded with two sheets of igneous rocks and considerable intercalations of gray shale. The upper part of the quartzite series is a thick-bedded quartzite, partly reddish but mostly white in colour. In this series ripple-marks and other indications of shallow water deposition have been frequently noticed. This group of sedimentary rocks may approximately correspond to the T'out'sun slates of the Hu-T'o region.

Above the quartzite series rests an immense thickness of cherty limestone, the apparent equivalent of the Tungyü limestone of the Hu-T'o area, of the Nankou limestone of the Nankou range, and of the "Siliceous Limestone" of the Western Hills of Peking.

Between the quartzite and the limestone is a bed of dark slate some ten meters in thickness. In this slate are found one or more layers of hematite ore, often resting directly upon the quartzite.

The iron ore which is embedded in this series, forms genuine seams and is a sediment just as truly as are the quartzites and slates which surround it.

The ore occurs in two distinct structural types:

1: Oölitic ore, composed of spheroids of hematite, as a rule with

*Contributed by J. G. Andersson

a nucleus of quartz, around which concentric hematite layers have been deposited.

2: Stromatolitic ore, with a very peculiar structure. It is built up of aggregates, in shape reminding one of elongated pears with the narrow end always directed downwards. The longest axis of these concentric structures is always nearly vertical and every one of them is composed of epicentric laminæ piled one upon another with the convex side upwards. The interstices between these aggregates are occupied by regular spheroids, identical with those composing the oölite ore.

Structures very similar in character to the stromatolitic ore, have also been observed in the cherty limestone overlying the ore beds both at Yen-Tung-Shan in Hsuan-Hua-Hsien, and in the canyon cut by the Hunho river through the mountains N.W. of Peking. These are all regarded as species of calcareous algæ, and are referred to above, as belonging to the genus *Collenia* of which three species are so far known in China.

Concentric structures of this type have been described in Europe and America under various names such as *Gymnosolen*, *Collenia* and *Cryptozoön*. Their organic origin has been strongly argued by several authors, whereas others consider them merely the products of chemical precipitation. It seems probable that they are, directly or indirectly, products of organic activities (algæ or bacteria), and if this is the case, they form the earliest traces of organic life hitherto noted in China.

The Nan-T'ou Tillite.*

A most remarkable occurrence of beds of glacial origin was discovered by Bailey Willis and Elliot Blackwelder in the middle

*Contributed by J. G. Andersson

course of the Yangtzekiang above the Ichang gorge, at Nan-T'ou village. In 1915 some additional observations were made by Dr. F.R. Tegengren.

The succession is shown in Fig. 5.

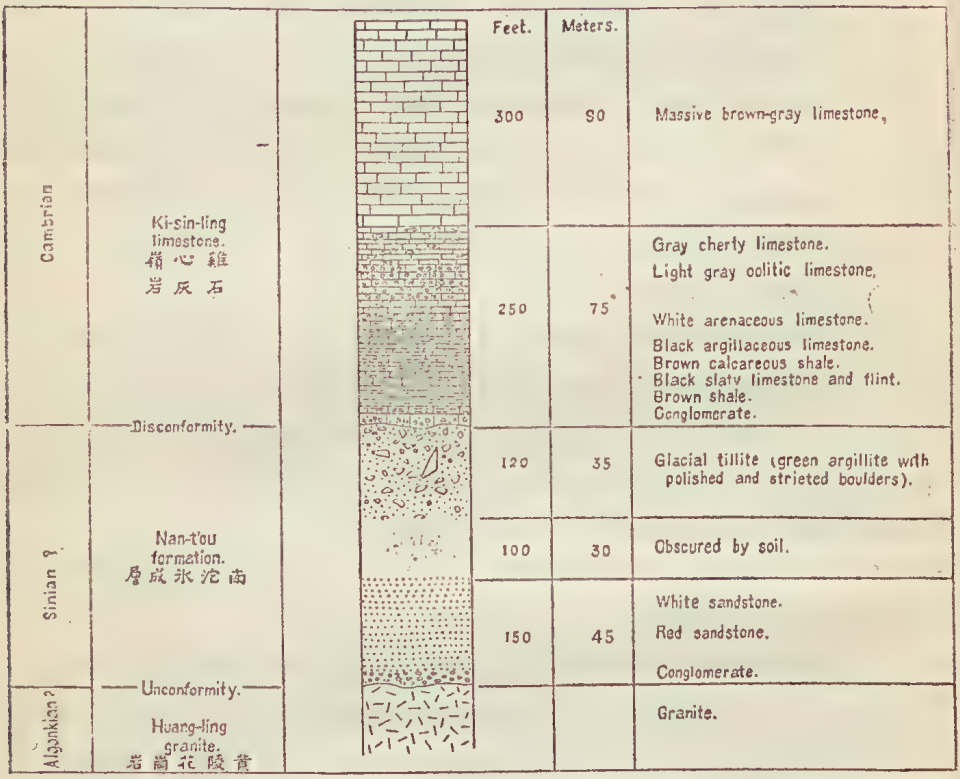

Fig. 5. Columnar Section of the Basal Palæozoic Strata at Nant'ou above the Ichang gorge of the Yangtzekiang (modified after Willis and Blackwelder). The Nan-t'ou tillite is disconformably succeeded by Cambrian strata. It is probably of Sinian age.

The oldest rock observed in this area is a gneissoid granite of Archæan or early Proterozoic age (Huang-Ling granite).

This granite is overlaid by a conglomerate with granite pebbles and above this basal conglomerate follow red and white sandstones to a thickness of 45 m.

After a gap of 30 m. covered by soil, follows a bed, 35 m. in thickness, of hard massive boulder-clay or tillite, in which lie stones

of various sizes and kinds, with their long axis at random angles with the horizontal. The rocks represented in these stones are very varied, including granite, porphyry, mica-schist, slate, limestone, quartz and chert. The stones range in size from sandgrains to blocks 50-75 cm. in length, and there is no assortment of the individual sizes. Coarse and fine particles lie mingled and chaotic in their arrangement. Many stones are angular, but the angles are smooth and rounded, the flattish surfaces are polished and scratched in exactly the same way as the pebbles in the Pleistocene boulder-clays of North America and Europe. The visitor to the Museum can compare the Nant'ou tillite boulders as exhibited in the Dynamic Section (Room C.) with the boulders of ground-moraine of Scandinavia.

That the Nant'ou tillite was formed by the action of a glacier or an inland ice is just as plainly proved as is the glacial origin of the Pleistocene boulder-clays or that of the Palæozoic tillites of S. Africa, India and America.

The Nant'ou tillite is overlaid by a limestone series in which Cambrian fossils have been found in an adjacent region. As no fossiliferous beds occur below the tillite, we must be satisfied to indicate the age of the tillite as early Cambrian or more probably Sinian.

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CHAPTER III.

THE CAMBRIAN SYSTEM.

The Cambrian system is well developed in China, and its strata are generally richly fossiliferous. This system has been studied more thoroughly than any other known to occur in China, and its fossils have been fully described, especially by Walcott* and Mansuy. All three divisions of the Cambrian are present, but they fall naturally into two provincial types, which from their probable origin may be designated the southern and the northern types. The former comprises the Lower Cambrian, the latter the Middle and Upper Cambrian.

The Lower Cambrian

So far as at present known, the Lower Cambrian deposits of the earth fall into three major marine provinces which were apparently completely distinct from one another. From their relationships to the main oceanic basins of the earth, they may be designated: 1, the Atlantic; 2, the Pacific; and 3, the Indian or Asiatic province. (See map Fig. 6)

The Atlantic province was chiefly restricted to the oceanic basin of that name, but had several known embayments in the bordering continents. On the west, or American side, one of these extended over eastern Newfoundland, New Brunswick and eastern Massachusetts; while on the east, or European side, there were two embayments, the Baltic and the Mediterranean. The waters of the first of these covered Wales and southern England, parts of Scandinavia, and the Baltic provinces of Russia, as well as the border lands on the south of the English Channel and the North Sea. The second

*Bibliography at the end of the Chapter.

embayment extended only partway into the Mediterranean area, covering a portion of southern Spain and France etc., the island of Sardinia and perhaps portions of the southern Mediterranean border of today. The southward extent of this province in the Atlantic basin is at present unknown.

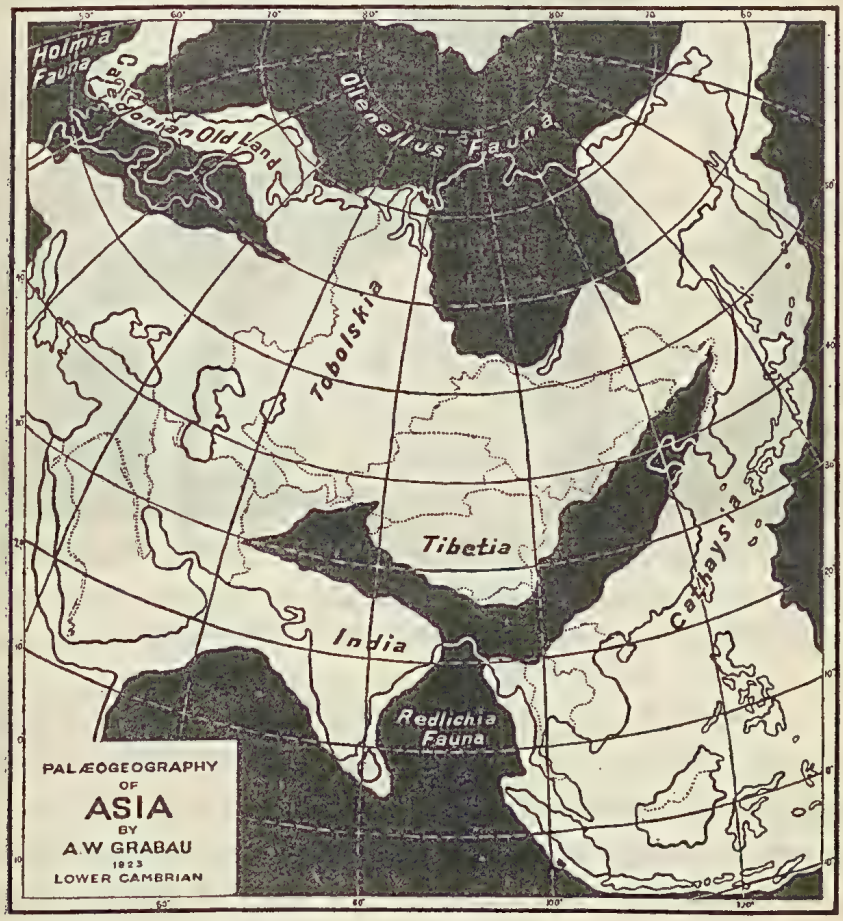

Fig. 6. Palæogeographic map of Asia showing the probable distribution of land and water (black) in Lower Cambrian time.

The waters of this marine province were characterized by a distinctive fauna, the leading members of which were trilobites of the genus *Holmia* and its sub-generic types. Besides this, there were primitive brachiopods and gastropods, and many species of the family

of Hyolithidæ. This fauna is wholly confined to the Atlantic province and its embayments; and throughout Palæo-Cambrian time, connections with other provinces seem to have been slight if not entirely wanting.

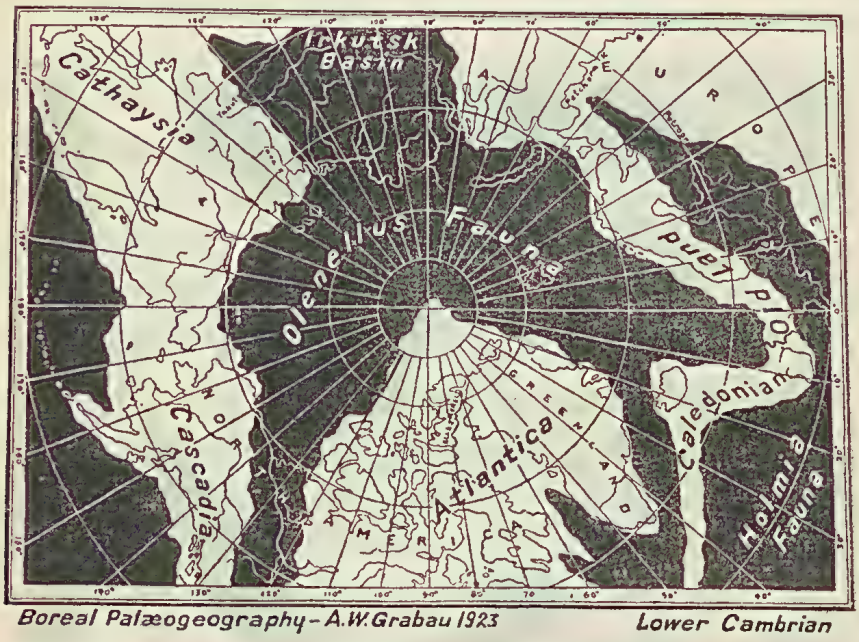

Fig. 7. Palæogeographic map of the Boreal region showing the probable distribution of land and water (black) in Lower Cambrian time, and the separate faunal provinces.

The Pacific province of the Lower Cambrian was more extensive than the Atlantic. In North America it occupied the two major geosynclines, the Appalachian on the east, and the Cordilleran on the west; but in Europe the deposits of this province are only known from the north of the British Isles. The fauna of this province is entirely distinct from that of the Atlantic province. In the place of *Holmia*, this fauna is characterized by the trilobite *Olenellus*, while the associated species are also entirely distinct from the associates of *Holmia* in the Atlantic province. This faunal distinctness is so pronounced, that we can only assume that the two provinces were separated throughout by land barriers, though in some cases these land

barriers were relatively narrow. Thus the deposits of the Atlantic province are known from eastern Massachusetts and from eastern Newfoundland; while those of the Pacific province, in the Appalachian geosyncline, are known from western Massachusetts and western Newfoundland, the distances in each case being probably less than one hundred miles. Here however, it must be recognized that these regions have been repeatedly folded since Cambrian time, so that we must consider that the original distances between the localities in which the two faunas are found were at least twice that of today if not greater. Again the *Holmia* fauna characterizes the Lower Cambrian rocks of Wales and England whereas the *Olenellus* fauna is found in the contemporaneous deposits of North Scotland (See maps, Figs. 6 and 7). Here again the intervening space has been much narrowed by folding and compression.

It is this Pacific type of fauna, which apparently characterizes the Lower Cambrian deposits of Arctic Asia, i.e. those of northern Siberia. From limestones on the Lena River Baron von Toll has described three species of *Microdiscus*, one of *Agnostus*, and fragments doubtfully referred to *Olenellus*, also a *Hyolithes* and two brachiopods one of which, *Kutorgina cingulata* Billings, is extremely characteristic of the Lower Cambrian deposits of the Pacific province.

The third province was entirely distinct from the other two, and apparently represented an embayment of the Indian ocean. This extended on the one hand into the Chinese, or Cathaysian, geosynclinal trough, the deposits being known from Yunnan on the south to Manchuria on the north, with intermediate points in Shantung and Shansi. A second arm of this embayment apparenty extended westward, along the Himalaya geosyncline, for these deposits are again found in the eastern Salt Range of north-west India, and their presence is indicated in the Himalayas at Spiti (See map Fig. 6).

They are also, though less perfectly known, in southern and western Australia.

The fauna of this Australo-Asian or Indo-Chinese province is entirely distinct from the faunas of the other provinces, though the known deposits are probably contemporaneous, at least with the latter part of the sediments that carry the *Holmia* fauna on the one hand, and those that carry the *Olenellus* fauna on the other. The leading form of the Asiatic province is the trilobite *Redlichia* (Fig. 8.) which is represented by a number of species. Associated with it is the trilobite *Palæolenus* and a number of brachiopods and ostracods. Within the Chinese geosyncline, the fauna seems to have been more or less of a unit, but in northwestern India it was more specialized, though the leading trilobite *Redlichia noetlingi* was scarcely distinct from the dominant Chinese form *R. chinensis*.

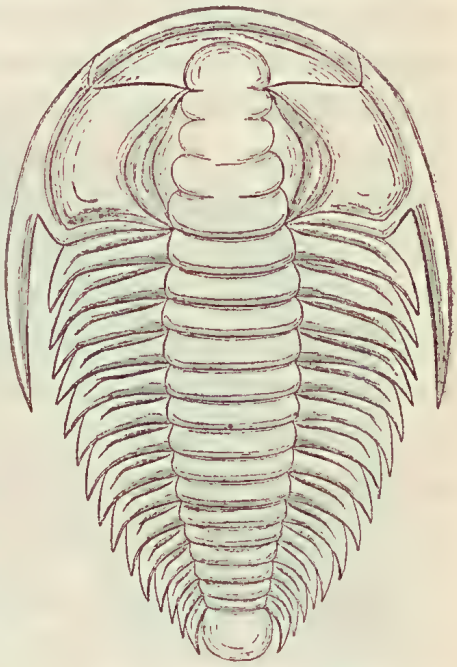

Fig. 8. *Redlichia chinensis* Walcott, (restored) natural size. Characteristic Lower Cambrian Trilobite.

Middle and Upper Cambrian

Rocks of Middle and Upper Cambrian age were extensively deposited within the Chinese geosyncline, where they are largely represented by limestones. They extend from Manchuria on the north to Tonking on the south, but they are still unknown in Yunnan. Middle and Upper Cambrian deposits are also found in the Himalaya geosyncline at Spiti where the Lower Cambrian is scarcely represented.

The Atlantic province was still distinct from the other provinces in Middle Cambrian time, being especially characterized by the trilobite *Paradoxides*, a genus entirely unknown outside of it. The Pacific and Indian provinces on the other hand, had become confluent to some

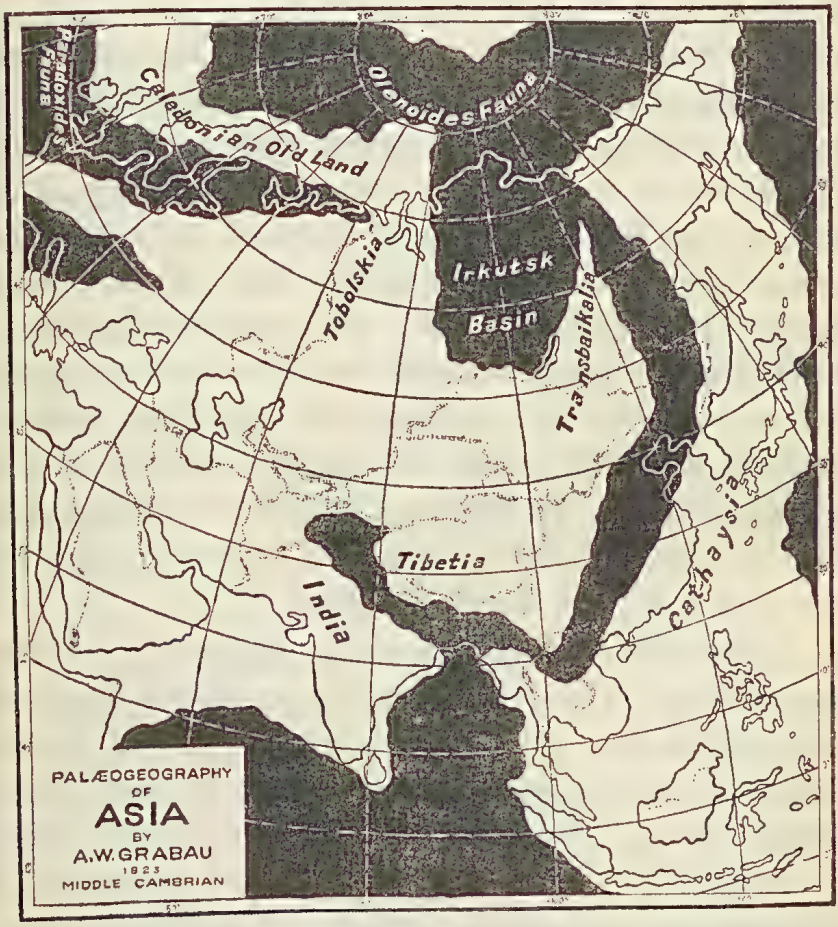

Fig. 9. Palæogeographic map of Asia in Middle Cambrian time, showing main invasion from the north with probable persistence of southern invasion in part; (water in black).

extent, so that the faunas of these provinces, though still maintaining a certain individuality, had nevertheless many features in common. This is especially the case with the Middle Cambrian fauna of Spiti in India, which is more closely related to that of western North America

than to any other Middle Cambrian fauna. Though having certain elements in common with the Middle Cambrian of China, it is on the whole sufficiently distinct from it to be a separate subprovince. This is not surprising when the geographical position is considered (Fig. 9).

It is quite probable that the Chinese geosyncline became more or less confluent in Middle Cambrian time with the west American geosyncline across the present Arctic region. That this connection was not very complete is shown by the occurrence in the upper part of the Middle Cambrian of China of distinctive trilobite genera not known from North America. These include *Damesella* (Fig. 21), *Blackwelderia* (Fig. 20) and *Drepanura* (Fig. 22), the most characteristic species of which are also known from Tonking. Other genera are *Teinistion*, *Stephanocare*, *Shantungia* and *Liostracina*. On the other hand, Walcott cites the following characteristic Middle Cambrian genera from North America, which are still unknown in China: the trilobites *Karlia*, *Ogygopsis*, *Burlingia*, *Zacanthoides*, *Oryctocara* and *Neolenus*, and the brachiopod *Nisusia*.

While then, there is still a marked distinctness in the Middle Cambrian faunas of the two regions, this distinctness disappears in Upper Cambrian time. The Upper Cambrian of China is essentially similar in its generic aspect to that of western North America, indicating that the connection between these regions had become a more continuous one. It is however still quite distinct from the Atlantic province. The Middle Cambrian of the Siberian region is still little known. Some of the species described from there show certain affinities with species known from China, but the relationship is not as close as one might have supposed. Possibly the connection between the two regions was not a very open one, though future discoveries may show the contrary. Towards the close of Cambrian time, however, the connection appears to have become more marked if we

may judge by the apparent presence of trilobites of the genus *Ceratopyge* in the Upper Cambrian of China. The typical species of that genus is most characteristic of the basal Ordovician rocks of northern Europe, advancing in the Baltic embayment from the north-east while the Atlantic graptolite fauna (Tremadoc) entered this embayment from the south-west. It seems probable that the genus *Ceratopyge*, appearing first in the Upper Cambrian of China, reached western Europe by the beginning of Ordovician time, having migrated across northern Siberia.

The Cambrian of South China and Indo-China.

Our knowledge of the Cambrian of South China and the adjacent area of Tonking in Indo-China, is based at present entirely upon the stratigraphic work of Deprat partly revised by Charles Jacot* and the palæontological studies of Mansuy. According to Deprat the succession of palæontological zones is as follows:

Upper Cambrian

Zone of *Ptychaspis walcotti* Mans.
Zone of *Ptychaspis angulata* Mans.
Zone of *Chuangia nais* Walcott.
Zone of *Billingsella tonkiniana* Mans.

Middle Cambrian.

Zone of *Damesella brevicaudata* Walcott.
Zone of *Acrothele matthewi* var. *eryx* Walcott, and *Obolus damesi* Walcott.

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*Deprat's work has been found to require much revision, a part of which has been done by M. Charles Jacot, the new chief of the Geological Survey of Indo-China. Much remains to be done, and the present summaries so far as they are based on Deprat's works, must be considered tentative. For the description of the fossils see Mansuy's papers listed in the bibliography at the end of the Chapter.

Lower Cambrian

Zone of *Redlichia carinata* Mans.

Zone of *Palæolenus douvillii* Mans.

Zone of *Acrothele orbicularis* Mans.

Zone of *Redlichia chinensis* Walcott (Fig. 8).

The Lower Cambrian is best known from the deposits now found in the eastern part of the province of Yunnan, (Figs. 10-13) where the formations consist of sandstones and shales which generally weather to a yellow or orange color. Fossils are common in the shales, and consist chiefly of trilobites and brachiopods. The genera *Redlichia* and *Palæolenus* predominate among the former, while the brachiopods include the genera *Obolus*, *Lingula* and *Acrothele*.

The succession of formations in Yunnan, as exposed in the valley of the Niu-lan-kiang, a tributary of the Yangtze, is as follows in descending order: (According to Deprat).

8. Yellow shale
7. Gray concretionary marls
6. Green shaly sandstones with *Redlichia*, *Palæolenus* etc.
5. Sandstones without fossils
4. Reddish and yellow marly shales with *Redlichia*, *Obolus*, *Aristozoe*, Phyllocarids etc.
3. Greenish shaly sandstones with *Acrothele*
2. Crumbly marl-shales with *Redlichia*
1. Green arkosic sandstones. Base not exposed.

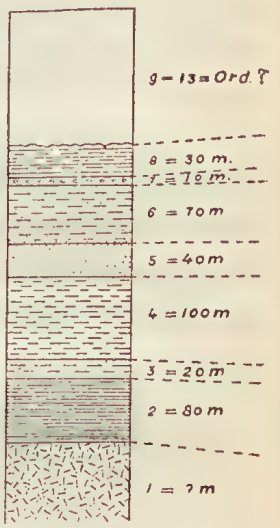


Fig. 10

Columnar section of the Cambrian rocks between Yi-lang and Sin-Kai-Tsu in East Yunnan (modified after Deprat). 1, Arkosic sandstone; 2, shales with *Redlichia*; 2, shales and sandstones with *Acrothele*; 4, shales with *Redlichia* and Phyllocarida; 5, unfossiliferous sandstone; 6, shaly sandstone with *Redlichia*; 7, concretionary marls; 8, yellow shales; 9-13, Ordovician (more probably Silurian) beds, etc.

The entire series has a thickness of over 300 meters, and the basal arkosic sandstones add another 300 meters where fully developed.

The fauna throughout is essentially a unit, and represents the later Lower Cambrian. The series corresponds essentially to the Mant'o shale series of north China. Older Lower Cambrian is absent in south China, this region having been land in early Palæo-Cambrian time, and subject to rock disintegration with the production of feldspathic sands, from which the basal arkosic sandstones were produced.

The nearest locality in which the rocks of this age are again found is in Shantung, about 1,300 miles (2,100 kilometers) to the northeast. Thence they extend north to Manchuria. The nearest locality in the other direction, is in northern India (Salt Range) 1,700 miles (2,700 km.) to the west. The Redlichia fauna is also

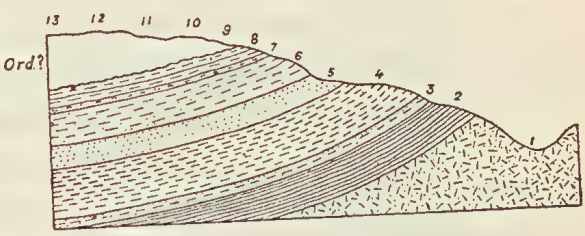


Fig. 11 Section between Yi-lang and Sin-Kai-Tsu East Yunnan, showing the succession of Cambrian strata (after Deprat) (for explanation of numbers see Fig. 10).

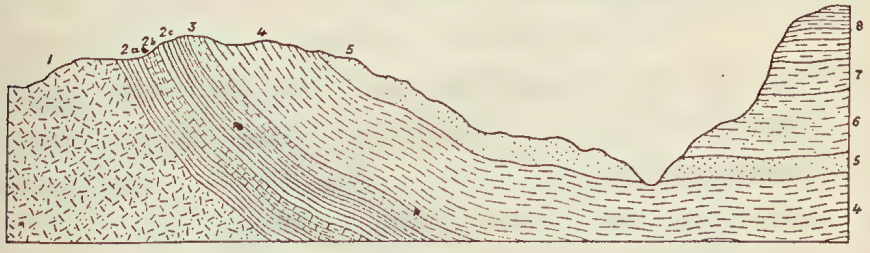


Fig. 12 Section of Cambrian strata at La-Ni-Tang, East Yunnan. 1, Arkose sandstone; 2a-2c, shales and limestones with *Redlichia*; 3, shales and sandstones with *Acrothele*; 4, shales with *Redlichia* and Phyllocarida; 5, unfossiliferous sandstone; 6, sandstone with *Redlichia*; 7, marls; 8, yellow shales; (after Deprat).

found in western Australia and in South Australia. This shows the very extensive distribution of this fauna over the Australo-Asian region

The sections (Figs. 10-13) modified after Deprat, show the relative thickness, and the structural attitudes and relations of these strata in eastern Yunnan.

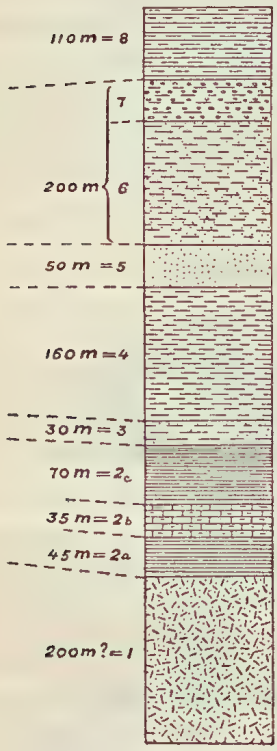


Fig. 13 Columnar section of the strata shown in fig. 12.

Middle and Upper Cambrian beds are found in northern Tonking and the bordering portion of Yunnan. The stratigraphy is involved, consisting of a succession of limestones and more or less sandy shales in repeated alternations, and followed by Middle Devonian strata. There seems to be much repetition by faulting. The fauna of this series is to a large extent that of the Middle and Upper Cambrian of north China. Of the 52 species identified, 19, or 36.5% are identical with species found in north China, 15 or nearly 29% are tentatively identified with south Chinese species, while 18 or about 34% are new species.

Characteristic Middle Cambrian brachiopod genera are *Acrothele* and *Obolus* while the trilobites include the genera *Agnostus*, *Agraulos*, *Anomocare*, *Blackwelderia*, *Conokephalina*, *Coosia*, *Damesella*, *Drepanura* and *Stephanocare*. Characteristic Upper Cambrian brachiopods are *Billingsella*, *Eoorthis* and *Huenella* while the trilobites include the genera *Chuangia*, *Crepicephalus* and *Ptychaspis*.

The Cambrian of North China.

(See maps Figs. 6 and 9)

The Cambrian of north China has been studied in the provinces of Shantung, Chihli, and Shansi, and in Manchuria. It rests disconformably (rarely unconformably) upon the Sinian rocks,

or unconformably upon the pre-Palæozoic crystallines. Upwards it is concordantly succeeded by the Lower Ordovician, which in some sections is thought to be conformable, with an intergradation, but in others is known to be disconformable with an erosion interval, and a conglomerate at the base of the Ordovician.

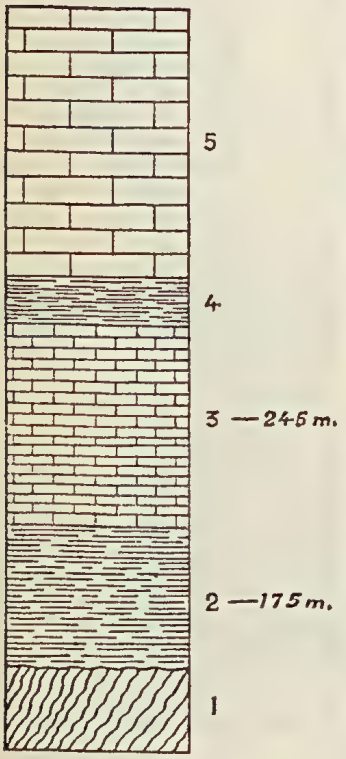


Fig. 14

Columnar section of the Cambrian and Ordovician strata in the Sintai district Shantung (Modified after Willis and Blackwelder). 1, *Taishan complex*, followed unconformably by 2, *Mant'o* shales, Lower Cambrian (southern type) 175 meters thick. Above this lies 3, the *Kiulung* Group of limestones, 245 meters thick of Middle and Upper Cambrian age (northern type). This is followed, probably with a disconformity by 4, Ordovician shale, above which follows: 5, the Ordovician limestones.

The subdivision of the Cambrian in Shantung is as follows (Willis and Blackwelder) (Figs. 14, 15):

SUPER-FORMATION: Lower Ordovician.

Probably a disconformity.

CAMBRIAN:

Upper Cambrian: Ch'aumitién limestone 400-600 ft. (120-185 meters).

Middle Cambrian:

Kushan shale 50-150 ft. (15-45 meters).

Ch'anghia limestone 400-500 ft. (120-150 meters).

Late Lower Cambrian:

Mant'o shales 500-580 ft. (150-175 meters).

Unconformity or disconformity.

SUB-FORMATION

Sinian System, or older systems.

THE LOWER CAMBRIAN.

MANT'O SHALES. These are the oldest known Cambrian strata of north China. In the province of Shantung, they begin with yellowish or greenish shales which rest directly upon

the peneplaned surface of the older rocks. Some thin earthy limestones occur in the series, but for the most part it consists of buff, maroon, yellow, and brown shales. In Shansi on the other hand, the Mant'o series begins with red sandstones and conglomerates, followed by red shales with interbedded thin impure limestones. In the Western Hills of Peking, it is a red shale series, divided by a heavy bed of limestone (Fig. 16).

The most typical fossils are:

Brachiopod: *Obolella asiatica*

Gastropod: *Helcionella rugosa* var. *chinensis*.

Trilobite: *Redlichia chinensis* (Fig 8).

Other species of *Redlichia* and of *Ptychoparia* occur, as well as other fossils. These have only been found in Shantung, the red shales of Shansi being apparently unfossiliferous. In Manchuria this horizon is represented by shales with *Redlichia* and by red unfossiliferous sandstones. These sandstones are in part at least, old Sinian sediments more or less reworked by the advancing Cambrian sea from the south.

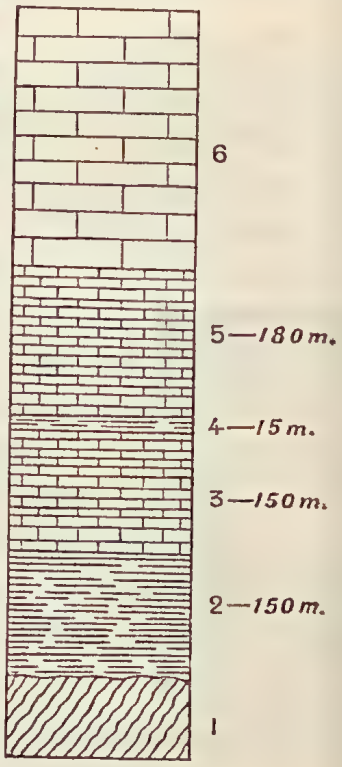


Fig. 15.
Columnar Section of the Cambrian and Ordovician strata of the Ch'ang-hia district in Shantung (Modified after Willis and Blackwelder) (scale same as Fig. 14). 1, Taishan complex; 2, Mant'o shale, 150 meters, (Lower Cambrian, southern type); 3, Ch'anghia limestone, 150 meters; 4, Kushan shales, 15 meters; 5 Ch'aumitién limestone, 180 meters (Upper Cambrian, northern type); 6, Ordovician limestone. (There is probably a disconformity between 5 and 6).

MIDDLE CAMBRIAN.

Ch'anghia Limestone. This consists of various shades of gray, and frequently oölitic limestone, especially in the lower part. Some shales also occur but the formation is predominantly calcareous. This

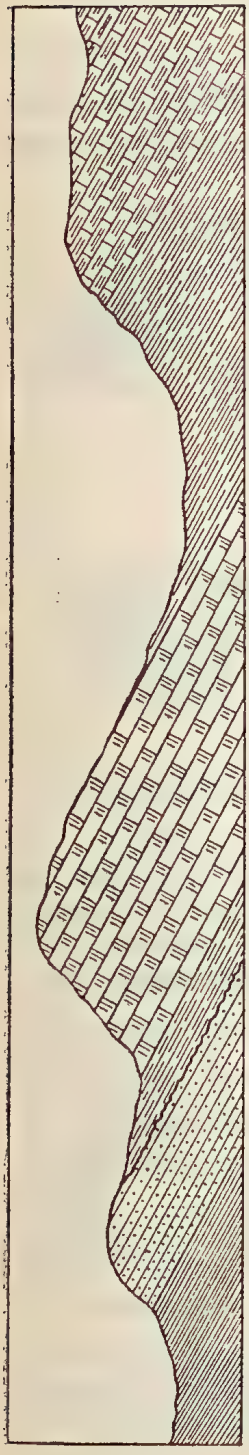


Fig. 16. Section along the Han-Ho opposite Chin-Yü-Kou, Western Hills of Peking, showing the relation of the Cambrian and Sinian rocks (Modified after L. F. Yih). 1-2, Upper Sinian formation (1 Hsiamaling shales; 2, Upper sandstone). 3-6 Cambrian strata, resting disconformably upon the Sinian. (3, basal red shale of Mant'o formation; 4, middle Mant'o limestone; 5, upper red Mant'o shale (3-5 Lower Cambrian); 6, Middle Cambrian limestone).

formation is richly fossiliferous, trilobites predominating. The genera *Ptychoparia* (Fig. 17), *Inouyia*, *Agraulos* and *Anomocarella* predominate in the lower part. Higher up the genus *Dolichometopus* becomes characteristic, while still higher up the fauna is characterized by *Dorypyge* (Fig. 18), *Crepicephalus* (Fig. 19), *Anomocarella* and *Dolichometopus*. The highest beds are characterized by the trilobite genera *Blackwelderia* (Fig. 20), and *Damesella* (Fig. 21), with spinous pygidia.

Kushan Shale. This is a green shale with thin shaly and conglomeritic limestones, with abundant remains of trilobites, the pygidia of *Drepanura* (Fig. 22) being especially striking. Large slabs of this shaly limestone, covered with pygidia and cranidia as well as free cheeks of trilobites, are often obtained, and form excellent museum exhibits. *Agnostus* (Fig. 23) and *Blackwelderia* are common. Smaller slabs, and shales with *Obolus* (*Westonia*) *blackwelderi* are also common.

In Manchuria, the Middle Cambrian is known as the Fuchóu Series. It is 500 feet or more in thickness and contains similar fossils (Fig. 17).

UPPER CAMBRIAN.

Ch'aumitién Limestone. This is a blue-gray limestone in Shantung, while in Chihli and Shansi this series contains much shale. Beds of intraformational (edgewise) limestone conglomerate (Wurmkalk) occur throughout the series, testifying to a shallow water origin. Trilobites are the most common fossils, the genera *Chuangia*, *Pagodia*, *Ptychaspis* (Fig. 24) and *Illænurus* (Fig. 25) predominating.

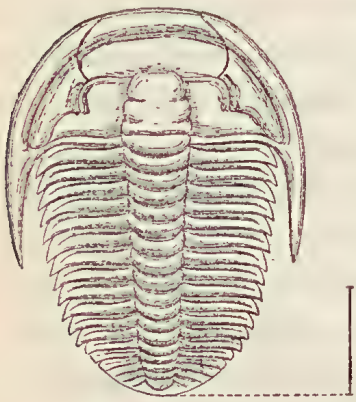


Fig. 17. *Ptychoparia kochibei* Walcott, enlarged. Middle Cambrian.

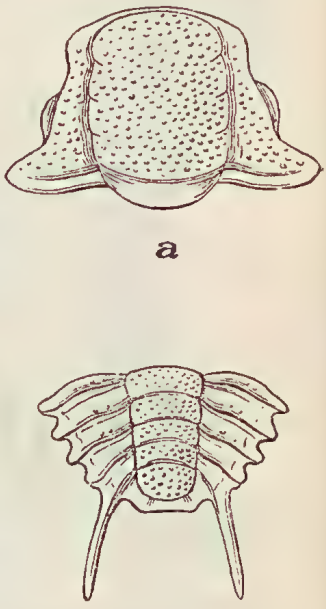


Fig. 18. *Dorypyge richthofeni* Dames, a, cranidium; b, pygidium. Middle Cambrian.

Fêngshan series. In Chihli province the highest beds are alternating shales and thin-bedded limestones (calcilutytes) characterized by trilobites (*Ptychaspis*, *Illænurus* and *Ceratopyge*) and by brachiopods (*Obolus* and

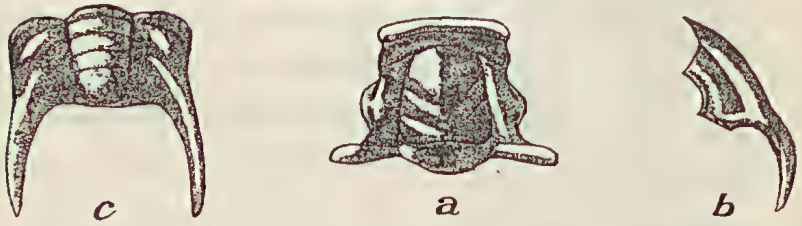
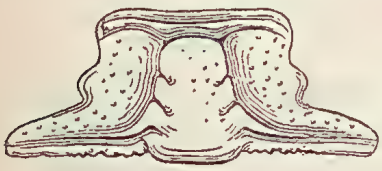


Fig. 19. *Crepicéphalus damia* Walcott; a, cranidium; b, free cheek; c, pygidium. Middle Cambrian.

Lingulella.) They are underlain by shales and thin limestones (Ch'anghia beds) and disconformably succeeded by the basal conglomerate of the Ordovician. (Sun: 21, 22).

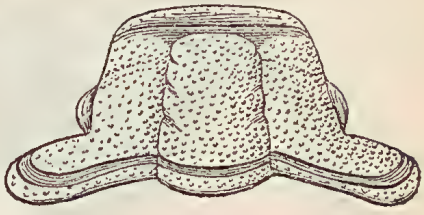


a

b

Fig. 20. *Blackwelderia sinensis* (Bergeron); a, cranidium, b, pygidium. Middle Cambrian.

Upper Cambrian beds have been found at Sha-Kuo-T'un, Fêngtien (Manchuria) resting disconformably upon the eroded surface of the Sinian limestone. This indicates continued transgression of the Upper Cambrian sea, with overlap of the later over the earlier Cambrian strata. The horizon represented in this part of Fêngtien is approximately that of the Ch'aumitién limestone of Shantung, for several of the characteristic species of fossils of that limestone are found in it.* The Fêngshan series seems not to be represented in Fêngtien, having probably been removed by erosion before the deposition of the Ordovician beds. This indicates that the sea with-



a

b

Fig. 21. *Damesella blackwelderi* Walc. a, cranidium; b, *pygidium*. Middle Cambrian.

*The fossils of the Upper Cambrian of Fêngtien, and of the Fêngshan series of Chihli, will be described and figured by Y. C. Sun in the Palæontologia Sinica.

drew again northward, at the end of Cambrian time, permitting erosion of the exposed area. Evidence for such erosion is seen in the

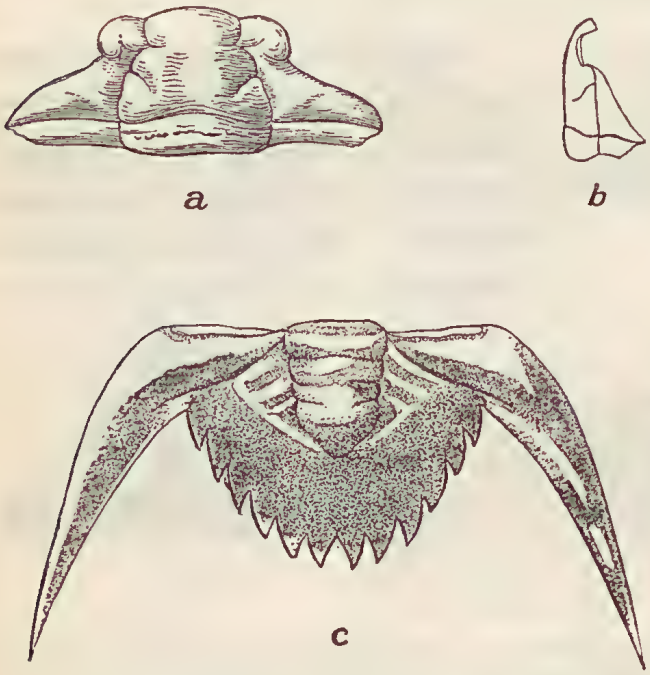


Fig. 22. *Drepanura premesnili* (Bergeron); a, b, cranidium; c, pygidium. Bat trilobite or Bat stone. Middle Cambrian.

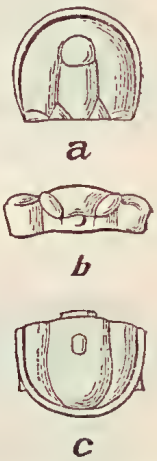


Fig. 23. *Agnostus chinensis* Dames. Middle Cambrian; a, cephalon×4; b, thoracic segment ×7; c, pygidium × 4.

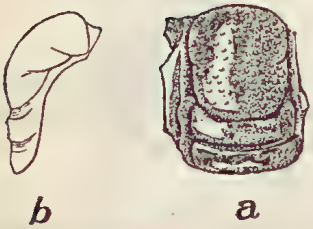


Fig. 24. *Ptychaspis acamus* Walc. Upper Cambrian.

Fig. 25. *Illænurus ceres* Walcott; a. cranidium, b. pygidium. Upper Cambrian.

contact of the Fêngshan limestone and the overlying Ordovician limestones in eastern Chihli (Kaiping basin). (See Figs. 33 and 34).

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CHAPTER IV.

THE ORDOVICIAN SYSTEM.

General Characters of the Ordovician.

At the opening of the Ordovician period of the earth's history, we again recognize the existence of a number of zoögeographical provinces, which at first were very distinctly separated, but later in the period became confluent to a considerable extent. Three of these provinces stand out with rather marked contrast, namely (1) the *Atlantic*, (2) the *Boreal* or *Arctic*, and (3) the *Pacific*. Whether or not there was a distinct Indian province, as at the opening of the Cambrian period, is not known, but it is likely that the Indian and Pacific provinces remained the unit which they apparently had become in late Cambrian time. It was especially during the Early and Middle Ordovician periods that the three provinces were most distinct; this being due to the fact, that during the greater part of Palæo-Ordovician time the seas slowly withdrew from the known lands, readvancing again as slowly during Neo-Ordovician time. Hence the Lower and Middle Ordovician deposits are commonly separated by a hiatus of varying magnitude, this being greatest in those regions from which the sea withdrew early and to which it returned late; and least in the regions of late emergence and early resubmergence. The general relationship of the successive members of the Lower and Middle Ordovician in the regions affected by this emergence and resubmergence is shown in the following diagrams (Figs. 26a and 26b), the first of which shows the actual relationships of the beds, while the second shows the progressive decrease of the hiatus in the direction of sea retreat. It is thus seen that in the region of non-emergence (right

of the diagram) all divisions of the Lower as well as the Middle Ordovician are present, whereas in the region of first emergence and last submergence (left of diagram) only the lowest member of the Lower Ordovician is present, this being followed disconformably by the highest member of the Middle Ordovician. Between these points

Fig. 26a. Diagram showing the relationships of the Lower and Middle Ordovician formations: C—Cambrian; B—Beekmantown (Lower Ordovician); Ch.-Chazy (Middle Ordovician).

older members of the Middle Ordovician rest upon younger members of the Lower Ordovician. The contact of the two series may be a simple erosion contact, this being sometimes masked by the reworking, during the advance of the sea, of disintegration products formed from the lower series during exposure, or a bed of sandstone may lie

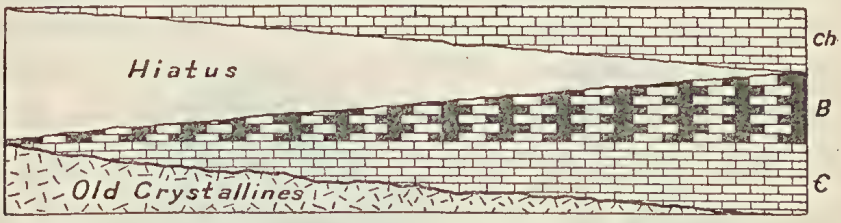

Fig. 26b. Diagram of the same series skown in Fig. 26a, with the strata parallel, so as to show the increasing hiatus (lettering as in Fig. 26a).

between the two main divisions, this sandstone often having characters suggestive of an eolian origin, due to reworking of the sands by the winds, during the period of exposure. (St. Peter sandstone of North America.)*

Evidence of such retreat of the sea with off-lapping of

*For further details see A. W. Grabau 9a and 11.

formations, during Lower Ordovician time, followed by re-advance of the sea, with overlap of formations during Middle Ordovician time, has been observed over wide areas in North America, in western Europe, and in eastern Asia (China), in other words wherever the Ordovician formations have been studied in detail. It is because of this relationship that the various sections of the Ordovician show such marked variability in thickness and such striking changes in the order of succession; and it is due to this peculiarity of history that the faunal provinces of the earth remained distinct in Early and Middle Ordovician time.

During the early part of the Upper Ordovician time, the transgressive movement of the sea, previously inaugurated, continued uninterruptedly for a time, and it was during this period that the several faunal provinces became confluent to a degree not before realized in the history of the earth. Hence we find that the Upper Ordovician fauna is a cosmopolitan type of fauna, being of very nearly universal distribution—at least in the present northern hemisphere. Towards the end of Ordovician time, however, a new factor became influencial in the shaping of events. This was the steady rising of the dominant land masses, a phenomenon which brought with it an extension of the terrigenous material derived from the erosion of these lands. This material spread in the form of great alluvial fans along the borders of the adjoining seas, which were pushed back simultaneously, the result being a wide-spread emergence of the lands. Wherever the rise of such old lands was athwart the direction of the prevailing winds, conditions of more or less marked aridity resulted on the leeward side of these land masses. Under such conditions, extensive oxidation of the sediments took place, because of the scarcity of vegetation, and after subsequent burial such oxidized sediments frequently assumed a red color from the dehydration of the iron hydrate which colored them. Thus we find, that in eastern North

America an extensive series of red beds (Juniata-Queenston), forms the higher members of the Ordovician, while in Siberia a similar series of red beds closes the Ordovician succession of that region. The Siberian red beds are further characterized by salt and gypsum deposits which testify to the prevailing aridity in northern Asia during the closing stages of Ordovician time.

It is quite probable, indeed almost certain, that similar emergences occurred in China during late Ordovician time. For we find that the higher Ordovician deposits are everywhere absent in this country, the youngest deposits of this period known, being late Middle, or early Upper Ordovician strata. There is no evidence that extensive continental sedimentation took place upon emergence, or was the cause thereof, and it is probable that the Chinese region was mainly subject to disintegration, without active erosion. This seems to be true at least for northern and central China, where the latest Ordovician horizon preserved is essentially the same over wide areas.

In central North America, in certain parts of Europe, and in China, the Ordovician deposits are to a large extent represented by limestones; but along the borders of the old lands, clastic deposits predominated. These clastic deposits are sometimes coarse sands and conglomerates, at other times shales and graywackes; and they are especially well known from the Appalachian trough of eastern North America (Hudson River Group etc.), and from the region of the Baltic geosyncline, where they

Fig. 27. Colony of a Graptolite (*Diplograptus*) restored, showing the floating bulb, the medusoid spore-sacs, and the pendent branches or rhabdosomes. (After Ruedemann).

now constitute the disturbed strata of Wales, England and Scotland; they occur also to a lesser degree in parts of Scandinavia. Where these sediments accumulated in the form of deltas and periodically exposed mud-flats along the margins of the sea, they generally include layers rich in *graptolites*, (Figs. 27-28) a group of organisms which was especially characteristic of the Ordovician and Silurian periods. These organisms led for the most part a floating, or planktonic, existence and they became stranded upon the mud-flats and delta surfaces whenever these were submerged during storm periods or exceptionally high tides, just as similar floating organisms become stranded on such surfaces under these conditions, along the modern sea-coast (14). As a result the thin mud-layers, which were deposited during such periods of flooding, frequently contain no other organisms than the remains of graptolites. The organic matter of these animals, together with the decaying sea-weeds which were stranded with them, commonly give these thin shale layers a strongly carbonaceous character and intensely black color. If such black layers are abundant, shales of this type may become the mother-rock of petroleum and other hydrocarbons, which, by migration, may accumulate in suitable porous rocks of contemporaneous age.

Because of their floating habitat, which insures wide distribution, and because of the fact that these organisms underwent rapid specific changes in the Ordovician oceans, the graptolites have become excellent index fossils; and it has become possible to subdivide the Ordovician and Silurian rocks into successive zones each of which is characterized by definite species of graptolites. Many such zones have been recognized, and the correlation of sediments at widely distant points has been possible on the basis of these graptolite zones. In China, Ordovician graptolite shales have so far been found only in western Yunnan, but though there are at present no similar deposits nearer than central Europe, it is quite possible to correlate the several

zones in the Yunnan region with the standard zones of western Europe and America*

Faunal Provinces.

We may now turn to a general consideration of the faunal provinces in Ordovician time and note the subdivisions of the Ordovician strata in each.

1. THE ATLANTIC PROVINCE.

The formations of this province are most typically developed in western Europe, though they are also known in some sections of north-eastern North America. The British succession has been made the type and is as follows:

British Subdivisions:

Upper Ordovician

5 Ashgillian (Ashgill beds) or Upper Bala.

4 Caradocian (Caradoc series) or Middle Bala.

Middle Ordovician

3 Llandeilan (Llandeilo series) or Lower Bala.

Lower Ordovician

2 Arenigian (Arenig series).

1 Tremadocian (Tremadoc shales).

There is in most places a disconformity between the Arenig and the Llandeilo, and another between the Caradoc and Ashgill beds, though the latter is perhaps of less significance than the former. This disconformity between Lower and Middle Ordovician is widespread over western Europe, south-western Britain being perhaps the

*It was formerly held that graptolite shales accumulated in deep water, and that the absence of other organisms in these shales was due to this fact. The character and distribution of these sediments, however, clearly show that they were shallow sea-margin deposits largely of deltaic type. See the discussion of this subject by A. W. Grabau and M. O'Connell in Bulletin of the Geological Society of America, Vol. 28, pp. 959-964, 1917.

only known region where the succession is continuous, if it actually is continuous there. (Grabau 10).

Over most of Great Britain, and on parts of the mainland as well, the Lower and Middle Ordovician horizons are chiefly represented by clastic deposits which, in places, reach a great thickness. These deposits include many graptolite horizons, the following having been recognized by Lapworth for great Britain:

British Ordovician Graptolite Zones:

CARADOCIAN

12. Zone of *Dicellograptus anceps*
11. „ „ *Dicellograptus complanatus*
10. „ „ *Pleurograptus linearis*
9. „ „ *Dicranograptus clingani*

LLANDEILAN

8. Zone of *Nemagraptus gracilis*
7. „ „ *Didymograptus geminus* (=*D. murchisoni* Fig. 28b)

Fig. 28a *Didymograptus bifidus* (Hall) (enlarged).

ARENIGIAN

6. Zone of *Didymograptus bifidus* (Fig. 28a)
5. „ „ *Didymograptus hirundo*
4. „ „ *Didymograptus extensus*
3. „ „ *Tetragraptus*

TREMADOCIAN

2. Zone of *Bryograptus kjerulfi*
1. „ „ *Dictyograptus socialis* (=*D.* (*Dictyonema*) *flabelliformis*)

Several additional graptolite zones are known from Sweden.

The calcareous or off-shore phase of these formations is well developed in the Baltic region, especially in parts of Sweden and in the Baltic provinces of Russia, though there as elsewhere the series is incomplete, there being a hiatus of varying magnitude between the Lower and the Middle Ordovician. The general succession in Sweden is as follows:

Swedish Subdivisions:

UPPER ORDOVICIAN.

Leptæna limestone (Ashgillian)

Hiatus

Trinucleus shales (Caradocian, in part)

Chasmops limestone (Caradocian, in part)

Macrourus limestone and shale

Echinosphærites limestone

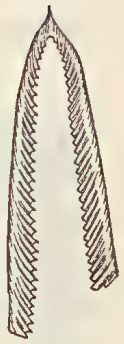

Fig. 28b *Didymograptus murchisoni.*

MIDDLE ORDOVICIAN (Llandeilan).

Orthoceras limestone (sens. strict.)

Ancitroceras limestone (*Illænus crassicauda, Asaphus rusticus, etc.*)

Chiron limestone (*Illænus chiron, Asaphus,* several species, *Endoceras bellemnitiforme*)

Platyurus limestone (*Asaphus platyurus, Endoceras bellemnitiforme*

Gigas limestone (*Megalaspis gigas*)

Asaphus limestone (Vaginatenkalk) (*Asaphus expansus, Megalaspis, Illænus, Nileus,* etc.) and *Vaginoceras vaginatum*).

Hiatus and disconformity.

LOWER ORDOVICIAN.

Megalaspis limestone (Lower Arenigian)

Limbata limestone (*Megalaspis limbata,* etc.)

Planilimbata limestone (*M. planilimbata, etc.*)

Ceratopyge limestone (Tremadocian) (*Ceratopyge forficula Eoörthis, Obolus apollinis,* etc.)

For middle Europe the characteristic succession is observed in Bohemia, though that region was probably in indirect connection only with south China. The Bohemian succession is as follows,—the series resting disconformably on Middle Cambrian, and being disconformably succeeded by Silurian.

Bohemian Subdivisions:

Upper Ordovician (Caradocian)

7. Zdice beds (D-d5 Barrande)..... ....600 meters
(*Trinucleus seticornis* etc.).
6. Zahorany grits, (d4) and
5. Trubiny black shales (d3) ....500 meters
(*Trinucleus concentricus* (=*T. ornatus*) *T. goldfussi* etc.).

Middle Ordovician (Llandeilan)

4. Drabov quartzites (d2.)..... ....175 meters
(*Dalmanites socialis*, *Trinucleus goldfussi*, *Asaphus nobilis* etc.).
3. Kvan-Osek beds (d1γ)..... ..... 70 meters
(*Placoparia zippii*, *Asaphus nobilis*, *Illænus katzeri*, *Niobe discreta*, *Aeglina prisca*, *Didymograptus geminus* etc.).

Hiatus and disconformity.

Lower Ordovician.

2. Komarov beds (d1β) (Lower Arenigian)..... 70 meters
(*Orthis desiderata*, *Harpides grimini*, *Amphion lindaueri*, *Didymograptus* (*Isograptus*) *caduceus*.
1. Krusna hora beds, (d1α) (Tremadocian?) *Lingula feistmantelli*.

In parts of the Mediterranean basin, as in Spain, the hiatus above the Lower Ordovician is very great, the latter being immediately succeeded by beds of Caradocian age, with a total absence of the Llandeilo. Among the characteristic early Upper Ordovician (Caradocian) brachiopods of the west European region, we may especially mention the following species, *Orthis actoniæ*, *O. vespertilio*, *O. calligramma*, *O. budleighensis*, *Dalmanella testudinaria*, *Plectambonites sericeus*, and *Strophomena expansa*. These or related species, are also found in the Upper Ordovician beds of south China, and this similarity of fauna clearly points to a connection of the south Chinese region with that of western Europe, though the precise path of intercommunication between these regions is at present not known. That

shown upon the Palæogeographic map (Fig. 29), is extremely hypothetic, as nothing is at present known of the occurrence of Ordovician strata in the intermediate region. In this connection it is important that we consider the Ordovician faunas of the Burmese

Fig 29. Palæogeographic map of Asia, showing the probable distribution of land and sea (black) in Middle Ordovician (Black River) time, and the sea in which the *Actinoceras* limestone was deposited.

region to the south-west of China, and those of the central Himalayas, for these most certainly lie along the path of migration of the faunas in question. The Ordovician formation of the Northern Shan States in Burma admit of the following subdivisions (Reed 32):

3. Nyaungbaw limestones
2. Naungkangyi Stage
    b Upper (?=Hwe Mawng Purple Shales)
    a Lower
1. Ngwetaung Sandstons.

The Ngwetaung sandstones have yielded only *Orthis* sp. and crinoid stems.

The Lower Naungkangyi beds are especially characterized by the abundance of their cystidian remains, but of the nine species identified, only three are also known from western Yunnan. The brachiopods include the genus *Orthis* with two local species and *Clitambonites* and *Porambonites*, the former with two species comparable to European forms, the latter with one (*P. intercedens* Pander). The pelecypods are new species, and so are two of the trilobites, while a third is compared with a European species (i.e. *Asaphus devexus* Eichw). Aside from the cystoids, marked in the list of Yunnan species by an asterisk (*), none of the species of this division are known from Yunnan. These beds may be of Lower Ordovician age but it is more likely that they represent early Llandeilan.

The Upper Naungkangyi beds carry a fauna very distinct from that of the Lower, only a few species being in common between the two. Cystoids are present, but less characteristic. The brachiopods include a number of characteristic Middle or early Upper Ordovician species, or varieties of the same, such as *Dalmanella testudinaria* Dalm., *Dinorthis porcata* McCoy, *D. flebellum* Sow., *Platystrophia biforata* Schl., *Orthis calligramma* Dalm., *Clitambonites squamata* Pander, and *Plectambonites llandeiloensis* (Dav.), besides several new forms. Trilobites are common but are mostly new species. They are however of European genera, and show on the whole a fairly close relationship to European species. They indicate the horizon of these beds to be essentially equivalent to that of stage C of the Baltic pro-

vinces of Russia, the Chasmops limestone of the Swedish succession, or the lower Caradocian (early Upper Ordovician) of Great Britain.

In the eastern part of the area there occurs a series of purple shales which have been named the Hwe Mawng beds. They overlie Naungkangyi beds of much reduced thickness and are believed to be in part at least the equivalent of the Upper Naungkangyi beds of the western part of the area, though these two have only about 25 per cent of their species in common. The Hwe Mawng beds lack the admixture of the Bohemian types of cystidians, and there is no trace of American affinities. The brachiopods are nearly all European species, including such characteristic forms, or varities of them, as *Dalmanella testudinaria* (Dall.), *Stropheodonta corrugatella* (Dav.), *Plectambonites sericeus* (Sowerby), and *Christiania tenuicincta* (McCoy). The trilobites, though for the most part new, are allied to European forms.

The Nyaungbaw limestone contains few fossils but the remarkable crinoid bulb *Camarocrinus asiaticus* (Reed) is found here. This species is also known from Yunnan. In addition this limestone has furnished *Scyphocrinus* sp, *Diplotrypa palinensis* (Reed), *Lingula* cf. *quadrata* (Eichw.), *Plectambonites repanda* (Salter), and *Orthis irravadica* (Reed). The beds are probably of late Upper Ordovician age (Ashgillian), or they may represent early Silurian.

The Ordovician beds of the Central Himalayas, have been especially studied in Spity and Niti, but are also known from other localities in the Himalaya and they probably extend a short distance into Tibet. The exposures near Muth and Shian on the Piu River are typical of this region. The series begins with 150 feet of shaly and flaggy quartzites, which rest uncomformably upon the Cambrian, and are followed by 300 feet of limestones, all more or less fossiliferous. The beds are said to be succeeded without a break by limestones, and later by sandstones, with an early Silurian fauna. The

Ordovician fauna of these beds is remarkable, in that its affinities with that of Europe on the one hand, and that of Burma on the other are of the slightest, while in spite of the marked individuality of the fauna, there seems to prevail a strong American element. Reed compares this fauna with the American Trenton rather than with any other known fauna. As Reed remarks, it is difficult to conceive the pathway of connection between this Indian and the American fauna. Perhaps this relationship is more apparent than real, the similarily being due primarily to parallelism in development in the two regions, for the American Trenton fauna is complex and was also to a considerable degree derived from European emigrants. If, as the Indian geologists believe, these Himalayan beds are of late Ordovician age and pass without break into the early Silurian deposits, we may conceive that such a parallel development might have proceeded in late Ordovician time within this more or less isolated area. On the other hand we might assume that, if this fauna has really an American stamp, it reached this area by way of the northern channel across China in post-Actinoceras time. If that were the case, however, it would be strange, were all the evidence of such a migration removed by subsequent erosion in China and in Burma, which regions would have to be regarded as lying in the pathway of such a migration. Reed cites a *Gonioceras* from the Himalayan fauna which would seem to support the idea of a migration from the north, but it must be confessed that the generic identification is open to grave doubt. Still another possibility presents itself, namely that an opening was formed on the south connecting the Himalayan geosyncline with the Indian ocean, as seems to have been the case throughout Cambrian time. But on such a supposition the absence of distinctively American types in Burma and in south China would be difficult of explanation. Evidently the problem requires more thorough investigation, and until more evidence is available it is perhaps better to consider the Spiti

fauna as a local one and that its suggestion of American affinities is more apparent than real and due to a certain parallelism in development.

2. *THE BOREAL PROVINCE* (*Figs. 30, 31*).

Of great significance for the understanding of the Ordovician formations of north China, is the recognition of the character and extent of the Boreal province in Ordovician time. Fortunately, enough of the distribution and character of the faunas of this province is known, to enable us to form a fairly complete picture of its geography and of the succesion of events which characterized it.

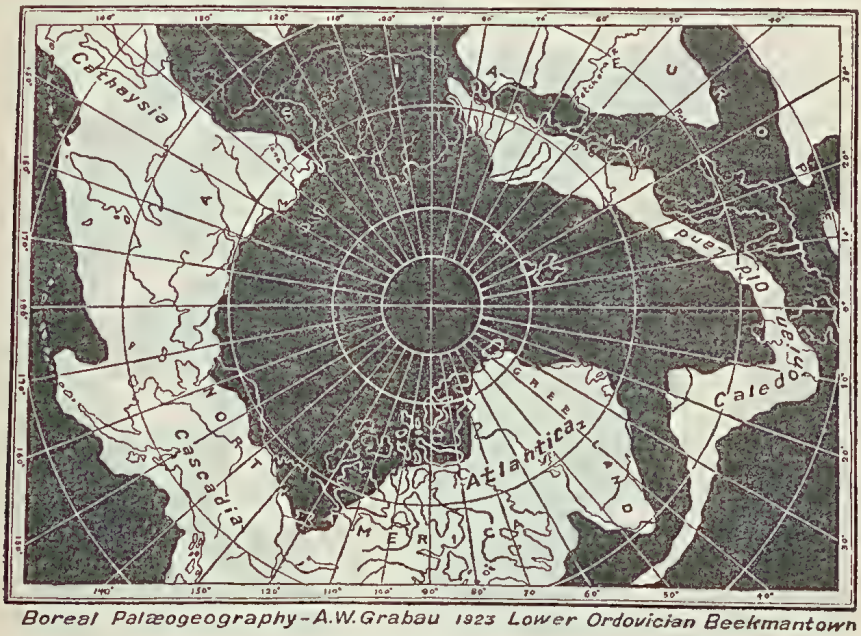

Fig. 30. Palæogeographic map of the Arctic region, showing the relationships of the marine waters (black) which covered Asia, to those of Europe and America, and the routes of migration of faunas in Lower Ordovician (Beekmantown) time.

In applying the name Boreal or Arctic to this province, we do not wish to imply that it was a cold-water province, or that it had any of the climatic and oceanographic features which at present

characterize the region in which it was located. Indeed, there is every reason for believing that in Ordovician time, as in the succeeding Silurian period, this province was characterized by mild climate, and that the waters were sufficiently warm to permit the growth of coral reefs, in regions which now lie within the Arctic circle. As has been repeatedly suggested elsewhere, such conditions are most satisfactorily explained by the assumption of a different position of the earth's axis during at least the earlier part of the Palæozoic era. Thus the name of this province has reference to its location with regard to the existing geographical regions, rather than to the character of the province as such.

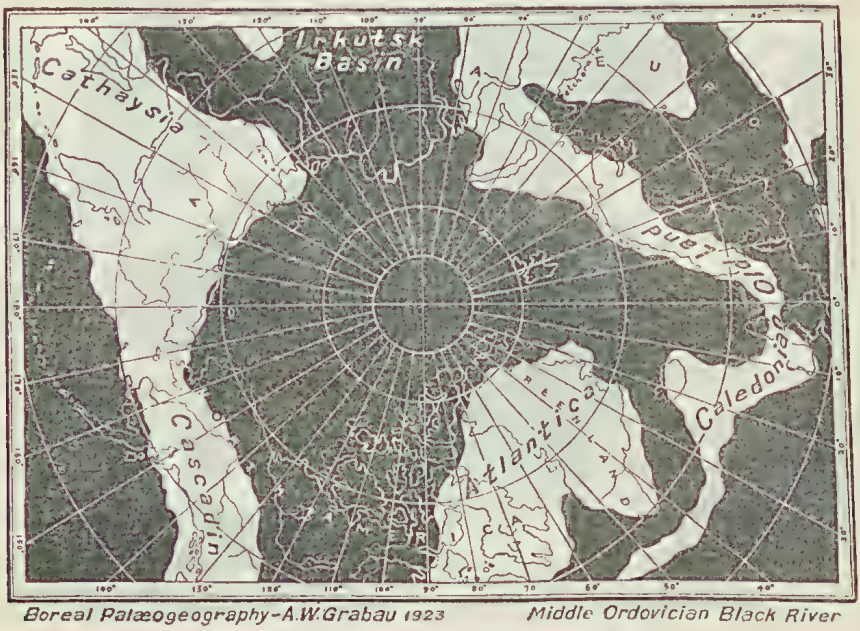

Fig. 31. Palæogeographic map of the Arctic region, showing the relationships of the marine waters (black) which covered Asia, to those of Europe and America, and the routes of migration of faunas in Middle Ordovician (Black River) time.

The general extent of the Boreal province in Early and Mid-Ordovician time is best seen by reference to the maps (Figs. 30-31). It comprised essentially the north polar region of today, with an

extension on the one hand into north-eastern North America along the line of the Appalachian geosyncline, and on the other into eastern Asia, along the line of the Chinese or Cathaysian geosyncline. Its southernmost extension was essentially coincident with the course of the modern Yangtze River, while on the north it broadened out into the Irkutz Basin of northern Siberia. The distribution of the faunas within this province, and their distinctness from those of the other provinces is so definite, that one can not question the reality of the existence of this province in Ordovician time, nor its almost complete isolation. It was indeed a center of organic evolution in Early and Mid-Ordovican time, and not until the end of the latter period did it come to have any pronounced connection with, and relation to the other provinces of the earth.

The subdivisions which have been adopted for this province are based upon the development of the system in the State of New York, in eastern North America; those of the Lower and Middle divisions being primarily derived from the succession of formations in the Champlain Valley. As has been noted, the deposition of Upper Ordovician strata was going forward in seas which to a certain extent had become confluent, so that we find that these late Ordovician formations contain a commingling of faunas in some cases of two in others of all three provinces. Bearing this fact in mind, we may take the succession of the Ordovican formations of the Boreal province as essentially conforming to the following divisions:

North East American Subdivisions:

UPPER ORDOVICIAN or Trentonian.

Queenston red shales (continental).

Lorraine shales and sandstones.

Utica shale and Trenton limestones (essentially equivalent formations).

MIDDLE ORDOVICIAN or Chazyan.

Black River limestone.

Chazy limestones.

Hiatus and disconformity.

LOWER ORDOVICIAN or Beekmantownian.

Beekmantown limestones.

Only the Lower and Middle divisions demand consideration in the discussion of the Boreal province, since the deposits of the Upper are no longer of a distinctive type.

The marked individuality of the Lower Ordovician or Beekmantown fauna of this province is seen in the dominance of cephalopod and gastropod life over other organisms. The former comprised to a large extent the *Endoceran* types, (especially *Proterocameroceras* and *Cameroceras*) together with the remarkable genus *Piloceras* (Fig. 41), and the still more strongly individualized genus *Chihlioceras* (Fig. 39). The leading gastropods belonged to the group of the *Ophiletas* (Fig. 40), though others were present as well. Finally the coral element was to a large extent represented by the Archæocyathid group, the genus *Archæoscyphia* (Figs. 37, 38) (type *A. minganensis*) predominating. This fauna is known from the St. Lawrence region of eastern North America, where it is found in north-eastern New York and the adjoining Canadian region, as well as on the Mingan Islands, and especially in western New Foundland (longitude 75° to 55°W). The name of this fauna is derived from *Beekmantown*, a locality lying east of the Adirondack Mountains in New York State. In the New Foundland region, the waters of this province were, for a period, in more or less interrupted connection with those of the Atlantic province, while farther south in eastern New York, there appears to have been a temporary junction with the southern or Pacific province (Gulf of Mexico extension).

The Beekmantown fauna is again found in the Durness limestone of northern Scotland (about long. 5° W.) the formation enclosing it resting disconformably upon beds with the Lower Cambrian

Olenellus fauna (Grabau 10). The Beekmantown fauna is however entirely absent from the corresponding Arenig beds of the Atlantic province which have their typical development in south Scotland, in England, and in Wales. Passing eastward along the border of the Boreal province we find its fauna again represented on Bear Island, between Spitzbergen and the Scandinavian coast (about longitude 20° E.). The next eastern region in which this fauna is found is north-eastern China (about longitude 120° E.), but it is not improbable that the Archæocyathid Torgashino limestones described by von Toll (35) from Siberia (Krasnojarsk on the Yenissei, about longitude 92° E., latitude 56° N. and in the Salair, about longitude 86° E.); belongs to this horizon rather than to the Cambrian. Finally, completing the circle, we come back to about longitude 75° W., but this time within the Arctic Circle. The fauna found in the rocks of Lower Ordovician age in southern Ellesmere land (*Clarkoceras holtedahli* Foerste, *Ellesmeroceras scheii* Foerste) (Foerste 6) is apparently this same fauna, though neither *Archæoscyphia* nor *Piloceras*, which are found in all the other localities, have been recorded from these beds.

The Chazy beds of the Middle Ordovician are best developed within the deeper portions of the Boreal basin, for the Chazy series was primarily a transgressive one. Therefore we must look for the series in it completeness, only in those regions where the Beekmantown series is likewise most complete. This is probably to be sought for in the region of western New Foundland; but farther south in the northern section of the Appalachian geosyncline, we still find the series well developed. Thus in the Champlain basin, where the Beekmantown series retains a thickness of about 1,800 feet the Chazy series is at least 900 feet thick. It here includes three distinct members, a lower characterized by *Orthis costalis*, a middle, especially marked by the predominance of *Maclurea* (*Maclurites*) *magna*, and an

upper in which the leading form is *Camarotœchia plena*. Farther south, in the Albany region of eastern New York, and the slate belt of the New York-Vermont region, the two series have dwindled to a minimum, only the lower members of the Beekmantown (Deepkill shales) being present, while of the Middle Ordovician only the higher member (Normanskill shale) is found. In this region, the shales carry the Atlantic graptolite faunas. It was this Albany axis, together with the clastic deposits formed over it, that made the chief barrier between the faunas of the northern (Boreal) and southern (Pacific) portions of the Appalachian geosyncline (Fig. 32).

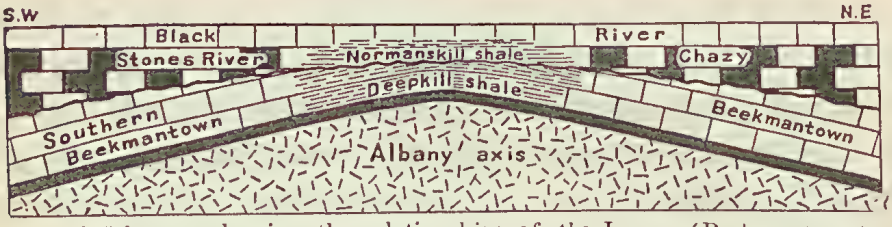

Fig. 32. Diagram showing the relationships of the Lower (Beekmantown) and Middle Ordovician (Chazy and Black River) of the Boreal province, to the same horizons of the Pacific province, along the N. E.-S. W. line of the Appalachian geosyncline in eastern North America, and the influence of the Albany axis, with its graptolite shales, in keeping the faunas of these provinces distinct until Black River time.

Some of the members of the Chazy series are found on the Mingan Islands in the St. Lawrence Gulf, and a very extensive portion of this series is found in western New Foundland. These lower divisions are not definitely known from north Scotland where they seem to be overlapped by the Black River horizon. On Bear Island too, the true Chazy appears to be absent; beds of lower Beekmantown age, with *Archæoscyphia* and *Piloceras* being succeeded by beds with a Black River fauna (Actinoceras limestone).

No true Chazy deposits are at present known from north China, where, so far as our present knowledge permits us to judge, the Actinoceras series (Black River) follows disconformably upon the

Beekmantown horizon which is characterized by *Archæoscyphia*, *Piloceras*, etc. It is not at all impossible, however, that further search will reveal the true Chazy horizon, and such search should be especially successful in the northern part of the geosyncline, either in China itself, or in the regions farther north.* For it must be noted, that the only possible direction of retreat of the sea from this trough in Lower Ordovician time was towards the north, and that in turn, the direction of re-advance in Mid-Ordovician time was from the north. Hence, the older members of the Middle Ordovician series should be looked for in the more northern regions.

Returning now to the Arctic region of North America, we find an instructive section an Bache Peninsula which forms a part of the eastern coast of Ellesmereland (75° to 79°16' north latitude and about 74° 30' west longitude) (Holtedahl 18). On this peninsula the light grayish-white "Orthoceras limestone" about 350 feet thick, which crops out midway up the vertical face of Cape Victoria Head and from which the Beekmantown cephalopods (*Clarkoceras* and *Ellesmeroceras*), above referred to, were obtained, is succeeded by a series of sandstones alternating with limestones, and then by a bed of close-grained brown limestone about 100 feet thick, which contains some fossiliferous layers. In these layers were found the gastropods *Hormotoma* and *Maclurea*, and the trilobite *Bathyuriscus*. From this same locality Etheridge (5) reports *Maclurea* (*Maclurites*) *magna* a typical Chazy fossil. It thus seems that these higher limestones of Victoria Head represent the Chazyan horizon, and that the sandstones separating them from the lower limestones mark the vicinity of the disconformity and hiatus which probably separate the two divisions here as elsewhere in the Boreal province. The typical Black River fauna is found in higher beds which crop out eight miles to the north

*Certain limestones in west Chihli province, carrying *Maclurea* may represent this horizon. They have not yet been studied in detail.

of Victoria Head, the strata there dipping to the north-westward.

Although the Chazy formation is known only from a few localities within the northern basin, the fact is well established, that it normally overlies the Beekmantown series, and underlies the Black River formation. If then we find, in widely distant localities, as in north Scotland, on Bear Island and in northern China, that beds with the Black River (*Actinoceras*) fauna rest directly upon beds with the Beekmantown fauna, this occurrence is sufficient to establish the existence of the hiatus between the two formations, and moreover indicates, that the break in succession covers the entire time of Chazy deposition, which we know to have been at least long enough to permit the formation of nine hundred feet of fossiliferous limestones in the Champlain valley. Though indirect, the evidence is none the less conclusive, and careful search in the regions involved will generally bring to light structural evidence of this break in succession.

If the known distribution of the typical Chazy formation is limited within the area of the Boreal province, that of the succeeding Black River division is as extensive as is the known distribution of the earlier Beekmantown. Indeed this division is not only found wherever the older division occurs, but in addition it appears to have a much wider distribution, resting by overlap in many sections directly upon older beds which belong to the other provinces. This is especially the case in North America, where, in the type region on the Black River, (west of the Adirondack Mountains in New York State) the Black River formation rests upon beds of Middle Ordovician age which were formed in the Pacific province (Lowville limestone). The same is true of this horizon in other parts of North America. This signalizes the confluence, at this stage of the transgression, of the Boreal waters advancing from the north (as we reckon compass directions today), and the Pacific sea advancing from the south.

The Black River fauna is as truly a biologic unit as was the

early Beekmantown fauna, and like that, was native to the seas of the Boreal province. Hence it is only where the transgression of this northern sea covered older deposits, that this fauna is found. Most marked among the elements of this fauna is the remarkable genus *Actinoceras* (Figs. 42-44) which is so characteristic of the strata that in some cases, notably in China, the formation is known by the name of "Actinoceras limestone". Associated with this form is the less specialized *Stereoplasmoceras* (Figs. 45-46) which forms a connecting link between *Actinoceras* and *Loxoceras*, the latter a typical Chazy cephalopod. Another type of cephalopod found in this fauna, and essentially restricted to it, is the remarkable genus *Gonioceras*.

Finally the Endoceratidæ already typical of the Beekmantown period, are to a certain extent still represented. Gastropods too are characteristic of this fauna, especially species of the genus *Lophospira*. Some of these may however have entered the fauna from the Pacific province. Much work is still needed before the faunas are fully differentiated.

3. THE PACIFIC PROVINCE.

We may now turn to a brief consideration of the characters of the third of the known Ordovician provinces, namely the one which we have designated the Pacific province. To a certain extent, this name is perhaps misleading, since we know practically nothing of the deposits of that period which were formed within the basin of the Pacific Ocean of today. Our only knowledge of the deposits here under consideration, and of their faunas, comes from the interior of North America, where sediments of this type are widespread, especially in the United States, and it would perhaps be more to the point to term this the North American province. However, since the waters which covered the interior of North America at this period, invaded that district from the region of the present Gulf of Mexico, and since

the Palæozoic predecessor of that water body was in communication with the Pacific across what is now part of Central America, and was separated from the Atlantic by the great continental mass of Appalachia, there can be little doubt, that the faunas of this interior American region originated in the Pacific of that period, however much they became differentiated in the North American epeiric seas, from the deposits of which alone we know them.

It is a regrettable fact, that the rich and peculiar fauna of the Lower Ordovician of this province i.e. the contemporaneous fauna of the Beekmantown and Arenig faunas, has as yet only partially been made known*. We know, however, that its elements were distinct from those of the other contemporaneous faunas, and that the dominant types were mollusks. The thickness of these Lower Ordovician beds is measured by thousands of feet in the southern Appalachians, but along the southern margin of the Adirondack Mountains (Mokawk Valley) it is only somewhat more than 300 feet (Little Falls Dolomite), while along the western border of that mountain region it is overlapped by the upper strata of the Middle Ordovician. Again in the upper Mississippi Valley (in Minnesota etc.), the thickness of this lower division is often less than a hundred feet. In all cases where the series is thin, the only part represented is the lowest, or one of the lowest members, the thickness increasing southward by the progressive appearance of higher members, after the manner of a typical retreatal series with off-lapping strata. The successive portions exposed during the retreatal movement of this Lower Ordovician sea, were covered by quartz sands washed from the northern shore outwards, and these were more or less extensively reworked by the wind during the period of exposure. Thus was formed the material of the St. Peter sandstone, a rock which consists in the main of uniform, well-rounded quartz grains, which retain all the characteristics im-

*Mr. E. O. Ulrich has an extensive unpublished monograph on this fauna.

pressed upon them by eolian activity. During the re-advance of the sea, in Mid-Ordovician time, these sands were in part incorporated as a basal bed in the transgressive series. As in all such cases, the successive members of the Middle Ordovician overlap one another, each coming to lie, beyond the edge of the preceding member, upon the eolian sands of the St. Peter sandstone. The higher division of this transgressive series of Middle Ordovician strata, is know as the Stones River group. Where it rests upon the lowest members of the Lower Ordovician in the region of earliest exposure, only its upper members are present, these having a combined thickness in places, of much less than one hundred feet, whereas the entire Middle Ordovician series in the more southerly regions, measures several thousand feet in thickness. (Grabau, 12).

The fauna of the Middle Ordovician of this province is likewise distinct from the faunas of equivalent age in the other provinces i.e. from the Chazy fauna on the one hand, and the Llandeilo fauna on the other. Now and then some elements of the fauna of the other provinces may be encountered, especially in the higher members, for it is quite probable, that during the period of transgression, connections with the other provinces may have become established.

Such a connection on a large scale became finally established during the period of deposition of the Black River beds, this connection being more pronounced with the Boreal than with the Atlantic province. The graptolite fauna of the latter however spread rather widely in the interior North American sea towards the close of Mid-Ordovician time (Normanskill fauna), as did probably also certain other elements of the Atlantic fauna. Such intercommunication of faunas between the several provinces became still more pronounced during the succeeding Trenton epoch, which in the interior of North America is represented by the Galena limestone. Finally in the latter part of the Upper Ordovician, the Cincinnatian period of American

history, the faunas became in large measure cosmopolitan. A more or less wide-spread re-emergence of the interior American region was inaugurated, with the beginning of continental sedimentation along the borders of the Appalachian old-land. As a result of this emergence, a varying amount of re-erosion of the previously deposited strata took place, so that upon the final transgression of the sea, towards the close of Ordovician time, these latest Ordovician beds (the Richmond series), generally came to lie disconformably, and with a hiatus of varying magnitude, upon older members of the Cincinnati group or even upon the Galena limestone itself. The Richmond transgression proceeded in part during the continuance of the deposition of the continental red Queenston beds, so that these two series more or less replace each other.

The close of the Ordovician was marked in western Europe, as well as in eastern North America, by the folding of the strata which had accumulated in the old geosynclines. No such folding is at present known to have occurred within the territory of China, though what appears to be a case of local folding, probably at the end of Lower Ordovician time, has been recorded by J. S. Lee from Honan (Lee 26).

Having now reviewed the general characteristics of the Ordovician deposits, and their history in the several known basins, we may proceed to a discussion of some of the details of the Ordovician strata of China in so far as these have been ascertained.

Ordovician Formations of North China.

The Ordovician formations of North China belong entirely to the deposits of the Boreal province, having been formed in an extension of the Northern Sea within the Chinese or Cathaysian geosyncline. The northern part of this geosyncline, which falls within the east Siberian region, is at present entirely unknown, but it is believed that it joins the north central Siberian, or Irkutsk, basin in

the region of Yakutsk, to the south of the Verkhoiank range. The deposits of Ordovician age within this trough are known from Fêngtien, Chihli, Shansi, Shantung, Kiangsi, Honan and northern Hupeh. The formations are chiefly limestone, and were originally thought to be a unit. Von Richthofen referred the limestones in most of these localities to the Carboniferous Limestone (Kohlenkalk) or the Mountain Limestone of Europe (Dinantian); Frech, Lorenz, and Willis and Blackwelder, however, recognized their Ordovician age. The latter named the entire series the *Tsinan limestone* from its occurrence in the vicinity of Tsinan-fu in the province of Shantung.

We now know that the series in question is not a unit, but comprises several distinct subdivisions. Moreover the evidence is at hand to show, that the lower and upper parts are separated by a marked hiatus, this being the wide-spread stratigraphic break which everywhere divides the Lower and Middle Ordovician.

The most detailed studies of this series have been made in eastern Chihli where the following subdivisions are recognized:

I. In the Kaiping Basin (Fig. 35)	II. In the Liu-Kiang Coal Field (N.E. Chihli, Fig. 36.)
Upper Ordovician	*Upper Ordovician*
(absent)	(absent)
Middle Ordovician	*Middle Ordovician*
Machiakou limestone 300 m.	(absent)
(Hiatus and disconformity)	
Lower Ordovician	*Lower Ordovician*
(absent)	Liangchiashan formation 275m.
(absent)	Shihmenchai formation 155 m.
Coralline limestone 200 m.	Peilintze formation 100 m.
Yehli limestone 200 m.	(Base not exposed).
(Hiatus and disconformity)	.....
Upper Cambrian	.....
Fêngshan limestone	....

The base of the Ordovician system is exposed in a number of localities along the northern rim of the Kaiping basin. The most instructive exposure is found in a ravine at the foot of Fêngshan, a hill about 2 li east of the village of Yehli. The following sections

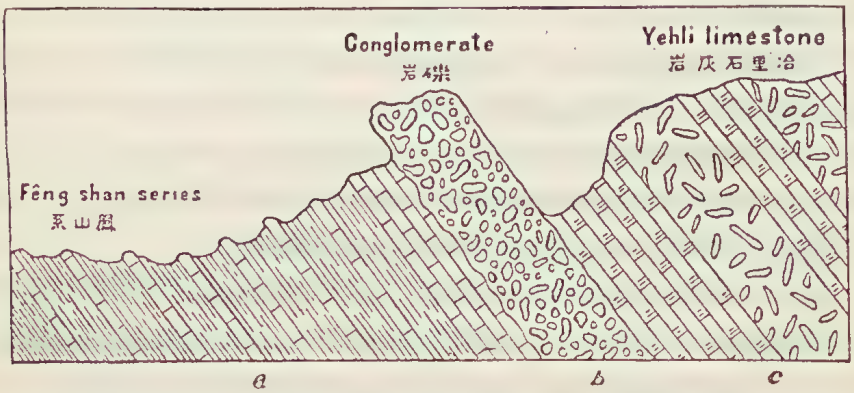

Fig. 33. Section of the Cambro-Ordovician contact and disconformity east of Yehli, Chihli; *a*, Fêngshan limestone (Upper Cambrian); *b*, Basal conglomerate, 1 m.; *c*, Yehli limestone (Lower Ordovician).

(Figs. 33 & 34) show the nature of the contact in this locality. The Upper Cambrian Fêngshan limestone is a thin-bedded lime-mud rock or calcilutyte, of light tan color on the weathered surface, the series

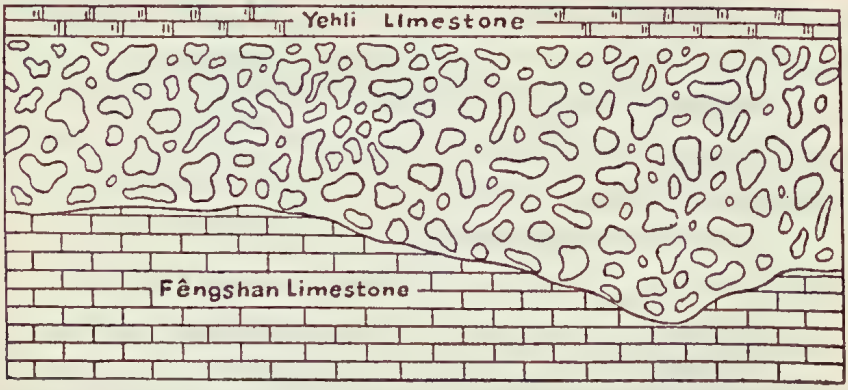

Fig. 34. Details of disconformable contact of basal Ordovician conglomerate on Upper Cambrian (Fêngshan) limestone, east of Yehli, Chihli.

passing downwards into more shaly members. Upon an irregular erosion surface, which marks the upper limit of the formation, rests a bed of limestone-conglomerate of a rather remarkable character.

The pebbles of this conglomerate consist entirely of the material of the Fêngshan limestone from which they were derived, while the matrix in which these pebbles are embedded is a finely granular or subcrystalline purplish lime-sand, the material being essentially that of which the succeeding higher limestones are composed. Where the surface of the conglomerate is exposed to weathering, as in the locality shown in the section Fig. 33, the pebbles stand out in relief, and their well-rounded and closely packed character forms a striking feature of the exposure, suggesting strongly the general appearance of a bed of unconsolidated river-laid gravels. In sections of the rock, the pebbles show considerable variation in form and size, but all of them have their corners well rounded. In size the pebbles range to an inch or more in major diameter, but most of them are much smaller. When broken, the pebbles show the olive-gray color and fine texture of the limestone from which they were derived, but the surfaces of the pebbles are always strongly oxidized to a deep brown color. This color is seen to form a marginal zone on the recently fractured faces, the color being deepest just below the surface and gradually fading away inwards. The thickness of the oxidized zone is usually a millimeter, being the same on pebbles of different sizes, and uniform, except at the ends of the pebbles, where, by confluence, the discolored portion may appear much thicker. Not infrequently the pebbles are pierced by small holes, apparently solution hollows in the original rock. These holes are filled with the purplish matrix, and are likewise surrounded by a zone of discoloration. But the most significant fact observed, is the absence of the zone of discoloration on fracture faces where the pebbles were broken shortly before becoming embedded in the matrix, while in those places, where the pebble was only partly chipped, the outer dark portion of the rind, or zone of discoloration, is absent on the chipped area, the deeper-lying, lighter colored portion alone remaining. The obvious conclusion to be drawn from these facts is, that the brown

rind or oxidized zone, was formed before the pebbles were embedded in the matrix, that is during the period which followed their formation, and while they were exposed to atmospheric influences. The coating has the characteristics of a "desert varnish", such as is formed on pebbles exposed in a dry climate for a long period of time. If such pebbles are broken or chipped when, in the transgressing sea, they are reworked into a basal conglomerate, these broken surfaces would be devoid of the oxidized zone, whereas if that zone were formed after the pebbles were embedded in the matrix, these broken surfaces should show the same degree of oxidation. These considerations lead to the conclusion, that the pebbles were exposed for a long period of time to atmospheric influences, and that, during this interval, the oxidized zone was formed on all the exposed surfaces, after which the pebbles were embedded in the sands of the transgressing Ordovician sea. During this process, some of the pebbles were chipped or broken, but the fractured surfaces were not again oxidized, not being any longer exposed. This would indicate that the interval between the retreat of the sea at the end of Cambrian time, and its re-advance in Ordovician time, was of long duration.

The conglomerate averages about two feet in thickness but in some cases this is somewhat greater. It is conformably succeeded by the normal dolomitic Yehli limestone, which in its lower portion frequently contains intra-formational conglomerates. These are composed of cake-like masses of the rock, embedded in a matrix of the same character, the cake-like "pebbles" usually lying in all positions instead of being parallel as in a normal water-laid conglomerate. Such layers indicate shallow water during their formation, with possibly temporary exposure, and probably gliding and fracturing of partly consolidated layers (Grabau 9 *b*, pp. 779-785). Such intra-formational conglomerates do not indicate a marked interruption in sedimentation as do the basal conglomerates before described. It is noteworthy that

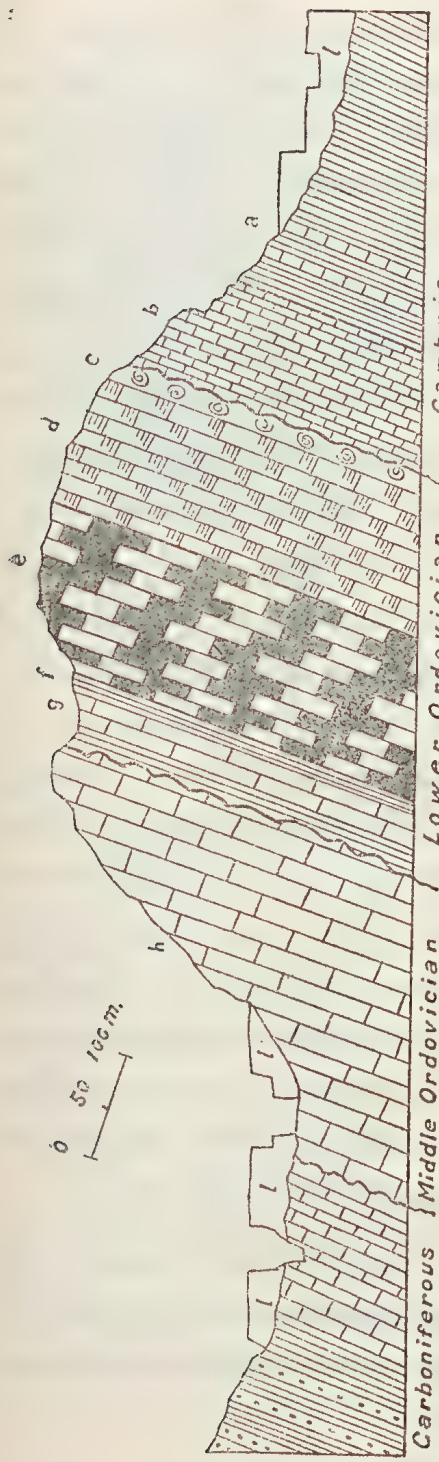

Fig. 35. Section of the Ordovician formations of Chang-shan, north of Chao-Kou-Chuang, Kaiping basin; *a*, Cambrian (Changshan formation); *b*, Upper Cambrian (Fêngshan? formation); *c-g*, Lower Ordovician; *c*, Ophileta bed; *d*, concretionary limestone; *e*, massive limestone (coral bed); *f*, shale; *g*, limestone; *h*, Machiakou limestone followed disconformably by Carboniferous (Taiyuan) sandstones (erroneously drawn as limestones) and shales; *l*,—loess (Y. C. Sun).

the fragments or "pebbles" of these intraformational conglomerates are not marked by the oxidation zone which is seen in the pebbles of the basal conglomerate.

The basal conglomerate is by no means always present at the contact. Indeed in the area of its typical development, there are sections in which it does not occur, but where instead, the Yehli limestone rests directly upon the Fêngshan limestone. In Chang-shan, the high ridge of limestone which forms the northern boundary of the basin near Chao-Kou-Chuang, the contact between the Cambrian and Ordovician is not marked by a conglomerate (Fig. 35). Here the *Yehli* limestone begins with beds characterized by *Orthis* and *Ophileta*. Elsewhere this limestone has yielded the "siphuncles" of the primitive cephalopod *Suecoceras*.

The thickness of the Yehli limestone in Chang-shan is about

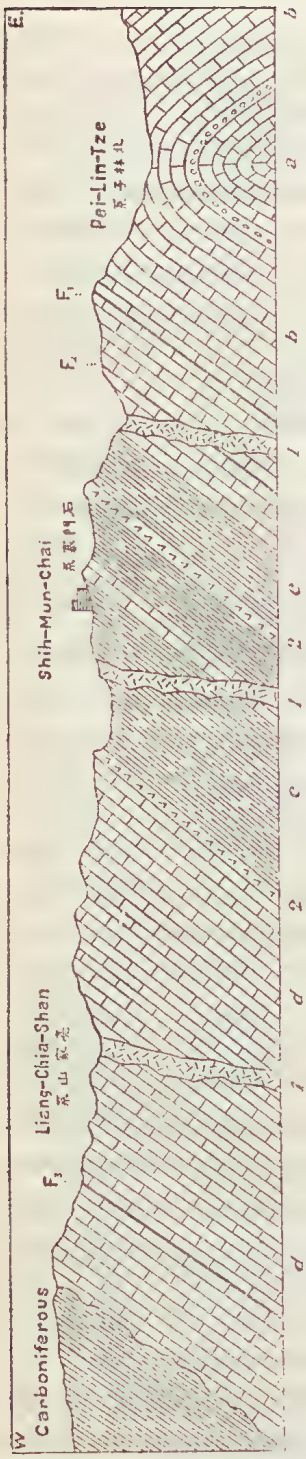

Fig. 36. Section of the Lower Ordovician formations of the Shih-Men-Chai region in North East Chihli; *a*, Cambrian; *b*, Peilintze formation, 95 meters exposed; *c*, Shihmenchai formation, 155 meters; *d*, Liangchiashan formation, 275 m. F.1, F.2, F.3, fossil localities. 1, intrusive dykes; 2, sills.

200 meters, and it is followed by another 200 meters or more of a coralline limestone, this being in turn succeeded disconformably by the Machiakou or Actinoceras limestone of late Middle Ordovician (Black River) age.

The Lower Ordovician strata are again well exposed in the Liu-Kiang Coal field (Shih-Men-Chai) in northeastern Chihli province, about 70 miles to the northeast of the Kaiping basin (Section Fig. 36). The base of the section is not exposed in this district, so that the full thickness of the basal series, the Peilintze limestone, is not known, that of the exposed part being 95 meters. It is probable, though not certain, that the Peilintze limestone horizon is above that of the Yehli limestone, which is, however, not exposed in this section.

The Peilintze limestone has two fossiliferous zones in the upper part, and these have yielded the following fossils:

Fig. 37. Restoration of *Archæoscyphia chihliensis* Grabau, about one-half natural size.

ARCHÆOCYATHINÆ

1. *Archæoscyphia chihliensis* Grabau (Figs. 37, 38).

GASTROPODA

2. *Ophileta squamosa* Grabau

3. *Fusispira* sp.

CEPHALOPODA

4. *Proterocameroceras mathieui* Grabau

5. *Chihlioceras nathani* Grabau (Fig. 39).

6. *Chihlioceras chingwangtaoense* Grabau

7. *Piloceras platyventrum* Grabau (Fig. 41), the latter doubtful from this horizon.

This is a typical Lower Beekmantown fauna, or the fauna of the Lower Ordovician of the Boreal province.

The Shimenchai formation, which succeeds the Peilintze, consists very largely of shales with intercalated limestones. It has so far yielded no fossils. The succeeding Liangchiashan limestones however, have yielded another typical Beekmantown fauna from a fossiliferous

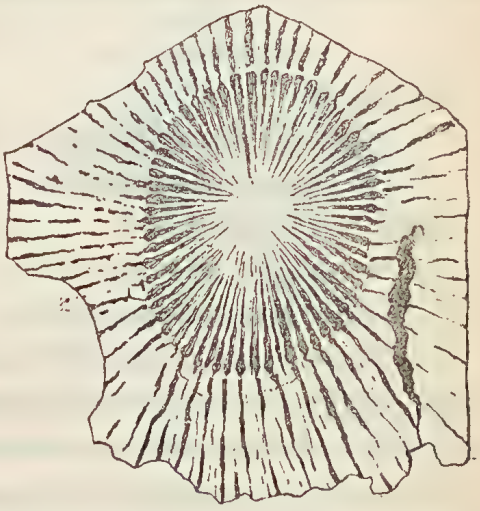

Fig. 38. *Archæoscyphia chihliensis* Grabau. Polished cross-section.

zone in the upper portion (Section Fig. 36 F3.) where the following species were obtained:

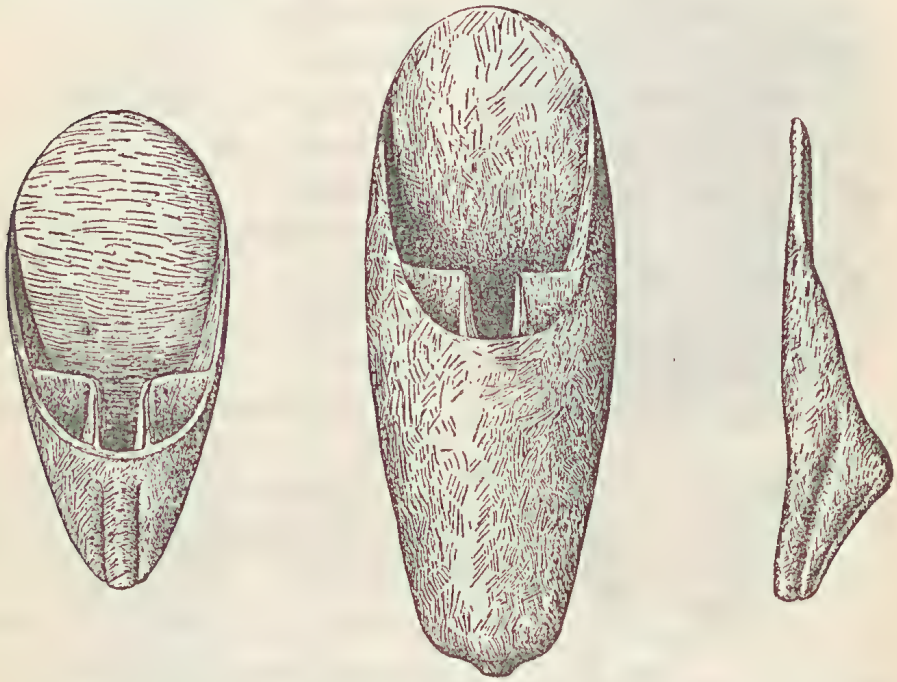

Fig. 39. *Chihlioceras nathani* Grabau; *a*, model of shell, restored (surface annulations omitted). *b*, model of final endosheath removed from shell; *c*, side view of same; all two thirds natural size.

GASTROPODA:

1. *Ophileta plana* Grabau (Fig. 40)
2. *Hormotoma doquieri* Grabau

CEPHALOPODA:

3. *Cameroceras styliforme* Grabau
4. *Piloceras platyventrum* Grabau (Fig. 41)

Fig. 40. *Ophileta plana* Grabau; side and top view of young shell × $1\frac{1}{3}$.

The Machiakou limestone is apparently absent in this region, beds of Carboniferous age (Taiyuan series?) succeeding the Lower Ordovician beds disconformably. The absence of this limestone is due to the post-Ordovician erosion which affected the whole of north China, and which extended deeper in this region

than in most others.

The Machiakou or Actinoceras limestone, which is so well developed in the Kaiping basin 70 miles south-west of the Shi-Men-

Fig. 41. *Piloceras plativentrum* Grabau; *a*, *b*, worn specimen; *c*, top view, (slightly reduced).

Chai region, is again found 200 miles north-east of this region at Hsiau Sörr in Fêngtien (Manchuria), the locality where von Richtho-

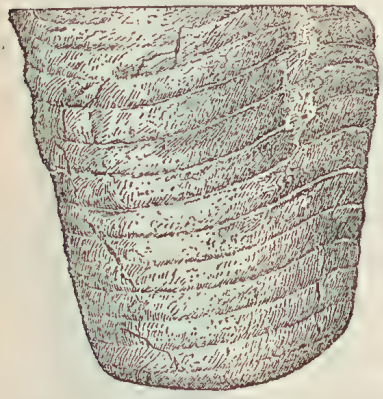

Fig. 42a.
Actinoceras richthofeni Frech; side view of shell.

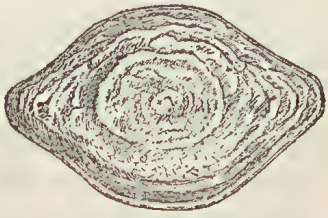

Fig. 42b.
Actinoceras richthofeni Frech; section.

fen discovered the first specimens of *Actinoceras* in Chinese rocks. Here the lower limestones appear to be absent, the Actinoceras beds resting by overlap directly upon the Cambrian strata.

The Machiakou limestone is the most wide-spread of the Ordovician formations of north China, its known extensions being from Fêngtien and Korea in the north-east, to northern Hupeh in the south-west, a direct distance of about 800 miles, and from central Shantung in the south-east to eastern Shansi in the north-west, a distance of about 250 miles. It is entirely unknown south of the Yangtze, where its place is taken by limestones with a European type of fauna. The age of the Machiakou limestone is late Middle-Ordovician, corresponding to the Black River, and perhaps the early Trenton (early Upper Ordovician) of North America. The fauna is the Black River fauna of the Boreal province, though there are found also a few elements of the European fauna (*Orthis calligramma*), just sufficient to show that a slight connection existed with the sea which then covered south China.

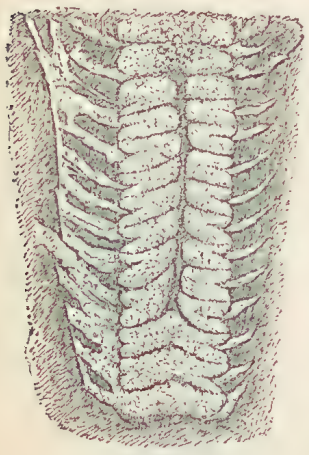

Fig. 43.

Actinoceras richthofeni Frech, longitudinal, section.

The cephalopods form the most important element of this Machiakou fauna. All of them belong to the group to which the modern *Nautilus* belongs, but they are for the most part highly specialized members of this group. The known species are straight-shelled or slightly curved forms, no coiled species having so far been discovered in this formation in north China. These occur however in beds of corresponding age in central China, being members of the southern fauna. The more characteristic cepha-

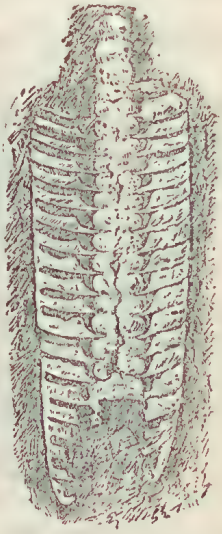

Fig. 44.

Actinoceras tani Grabau, weathered section.

lopod genera are *Actinoceras*, *Cyrtactinoceras*, *Gonioceras*, and *Stereoplasmoceras*. Others, also represented in the southern fauna, are *Cycloceras* and *Vaginoceras*. A brief characterization of each of these is here given:

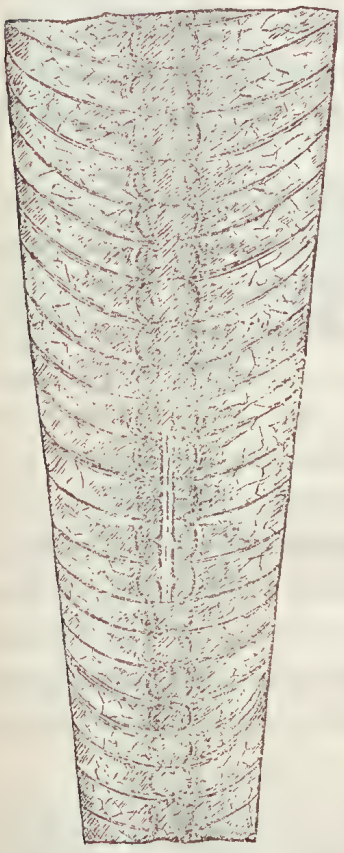

Fig. 45. *Stereoplasmoceras pseudoseptatum* Grabau; — median section.

ACTINOCERAS (Figs. 42-44) This fossil is among the most common in the Middle Ordovician limestones of north China, and from it the formation is often called *Actinoceras limestone*. The shell is tapering, cylindrical or compressed, and divided into many chambers by transverse septa. Unlike the similar straight shells of the Silurian and Devonian, the chambers of the *Actinoceras* shell are always more or less filled with stereoplasm, i.e. calcium carbonate deposited there by the animal. The central tube or siphuncle swells into a series of beads or nummuli, the whole resembling one of the elements of the Chinese calculating frame or *Suanpan* (算盤), one of the species being named accordingly *Actinoceras suanpanoides*. The nummuli are however filled by regular deposits of stereoplasm (organically deposited calcium carbonate) leaving only a narrow central tube or endosiphuncle, visible in some of the sections. The first species found in China was *Actinoceras richthofeni*, (Figs. 42-43) a large rapidly tapering form of oval section. *A. tani* (Fig. 44) and *A. suanpanoides* are among the common species, while *A. nanum* is the smallest known form.

CYRTACTINOCERAS. This genus is related to *Actinoceras*, differing from it in the gentle curvature of the shell, and in the form

which is short and relatively stout. Its internal structure is like that of *Actinoceras*.

GONIOCERAS. This is a compressed shell of similar character. The chambers are however empty, and the septa are not regularly concave as in the preceding forms, but are sharply bent down again in the outer half, though this part is commonly broken away in the specimens. The genus is rare in China, and like *Actinoceras* is otherwise known only from the late Middle and early Upper Ordovician of North America and the Arctic region.

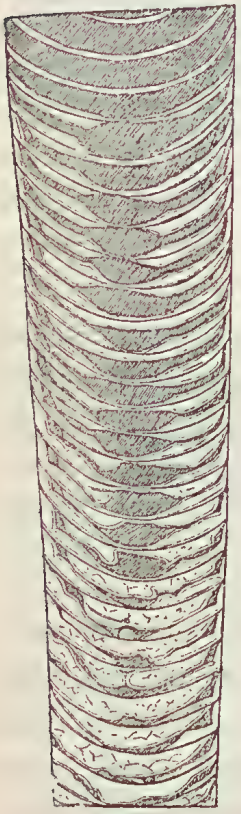

Fig. 46. *Stereoplasmoceras pseudoseptatum* Grabau. Sub-median section.

STEREOPLASMOCERAS. (Figs. 45, 46). This form is intermediate between *Orthoceras* (or *Loxoceras*) and *Actinoceras*. Its chambers are partly filled with stereoplasm, and there are generally additional partitions or *pseudosepta* (especially in *Stereoplasmoceras pseudoseptatum* (Fig. 46). The siphuncle is nummuloidal as in *Actinoceras*, but not filled with regular layers of stereoplasm. Instead, it is commonly filled with lime-mud only (being empty in the shells before burial and fossilization), or there is an irregular deposit of stereoplasm quite different from that found in *Actinoceras*. The genus is common in the Ordovician of north China and resembles *Orthoceras*.

CYCLOCERAS. This is a member of the *Orthoceras* group, but the shell is marked by concentric annulations or rings which give it a distinctive appearance. This genus is also common in the Ordovician of central China (See Fig. 70).

VAGINOCERAS. This is a rare form in the Upper Ordovician of north China, but common in this horizon in central China. It has a large siphuncle, filled with organic lime-deposits (stereoplasm), which consists of a succession of funnel-

shaped sheaths, with solid lime-deposits between these. Frequently the siphuncle is alone preserved, the outer shell having been worn away.

Fig. 47. *Eccyliopterus kushanensis* Grabau, top and section.

Another class of Mollusca, that of the gastropods, is also well represented in this fauna. Among the more characteristic genera are the following: *Eccyliopterus*, a flat shell with sunken spire and marked keel-like shoulder angle (Fig. 47); *Lophospira*, a high-spired form with flat shoulder and sharp keel-like shoulder angle, characterized by a notch (Fig. 48); *Pagodispira*, a similar form, but drawn out into a long spire (Fig. 49); and *Liospira*, a low broad-spired form, the shoulders of the successive whorls forming a continuous slope, and the flat lower side of the whorls showing a large umbilicus (Fig. 50).

Fig. 48. *Lophospira morrisi* Grabau × 2.

Among the Brachiopoda, *Strophomena* is the most common genus, but the specimens are seldom well preserved. *Orthis calligramma*, (Fig. 67) a southern form, is also sometimes found. Trilobite fragments of the genus *Asaphus* are not uncommon, but they are rarely well preserved.

In the Kaiping basin, where the Machiakou limestone rests disconformably upon Lower Ordovician limestones, and is disconformably succeeded by shales and sandstones of the Taiyuan series (late Dinantian), the thickness of

this rock is perhaps 300 meters. Whether its lower part represents a part of the Chazy series is still unknown, but this seems likely.

Fig. 49.
Pagodispira derwiduii Grabau.—× 2.

Near the western border of Chihli, at the Ching-Hsing Coal mine, a short distance west of Hwo-Lu-hsien, the limestone, some distance below the summit, carries *Maclurea* of the *M. magna* type. This may represent the Chazy horizon.

In Shantung, the Machiakou limestone has a wide distribution, but fossils are known chiefly from the upper portion, where *Actinoceras* is as usual the dominant type. Willis and Blackwelder included this limestone in their *Tsinan* formation, to which they assigned a thickness of 850 meters. They recognized two divisions in this limestone series: a lower, which is "a variable sequence of light-colored argillaceous limestones or dolomites and thin shales" without fossils; and an upper, a brown dolomitic limestone of fine texture, and occurring in massive strata. The upper member comprises about nine-tenths of the series, and carries the *Actinoceras* fauna in the higher part. How much of it is to be assigned to the Machiakou limestone is at present unknown. Nor is it known whether the succession is continuous throughout the higher series. If it is continuous, it is likely that a part of the series represents the Chazy

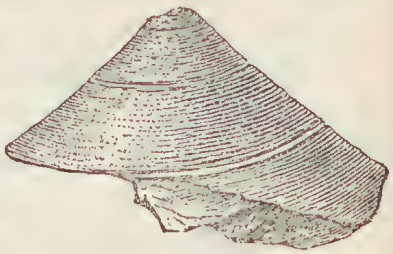

Fig. 50. *Liospira barbouri*. Grabau (enlarged × 2⅛).

horizon. No disconformity was recognized by Willis and Blackwelder between the two divisions of their Tsinan formation, but this may exist, and indeed, evidence of it has recently been found by Mr. Sun. It is quite probable that the lower unfossiliferous portion represents a part of the Lower Ordovician, though at present there is no palæontological evidence to substantiate this assumption.

The thickness of the Machiakou limestone, and its relation to other formations, in other parts of north China are still unknown, but its presence over wide areas is recognized by the occurrence of the characteristic fossils, especially the genus *Actinoceras*.

Ordovician Formations of Southern and Central China.

The Ordovician of southern and central China belongs to the deposits of the Atlantic European type, and, as has been previously stated, these faunas are in all essentials distinct from those of corresponding horizons in north China, while they show a remarkable correspondence with the faunas of contemporaneous deposits in western Europe. Indeed many European species re-appear in China practically without modification, though others show a certain amount of individuality, and although related to European forms, are nevertheless distinct species. As has been outlined in previous pages, the line of migration from Europe into southern China was by way of the Himalayan geosyncline—the region now characterized by some of the loftiest mountains of the earth, but which in Palæozoic time was a trough of subsidence, repeatedly flooded by marine waters, and in most periods, the principal highway of communication between the seas which covered China and those which covered Europe. The localities which have furnished Ordovician fossils are already quite numerous, but there are many others, the study of which will yield a rich harvest of facts which will bear upon the Ordovician history of China.

Yunnan.—Lower Ordovician strata are at present unknown

in south China, though they may exist there. Middle Ordovician formations are, however, well developed in western Yunnan though the Ordovician appears to be wholly wanting in eastern Yunnan. Three localities have furnished fossils of Middle Ordovician age, namely Pupiao (蒲縹) (Lat. 25° 2′ N. Long. 99° 6′ E.); La-meng (Lat. 24° 44′ N. Long. 98° 58′ E.); and Shih-tien (施甸) (Lat. 24° 45′ N. Long. 99° 12′ E.)

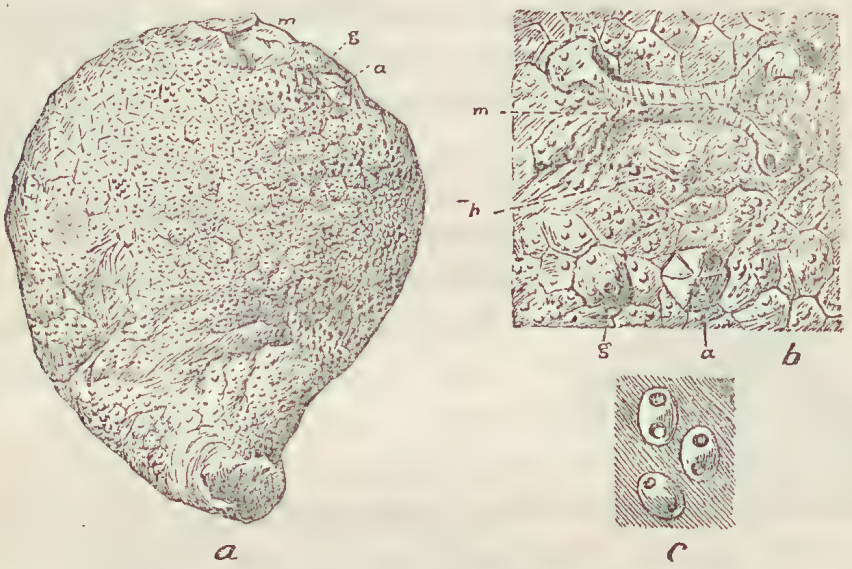

Fig. 51. *Sinocystis loczyi* Reed. Shih-tien; a, slightly compressed specimen, ⅔ nat. size; b, upper or mouth area, enlarged × 2½. (*m*=mouth, *a*=anus, *h*=hydrospire, *g*=gonopore); c, partly worn plate, showing tubercles with diplopores (respiratory? pores) × 7. (After Reed.)

"The Ordovician beds [of the Pupiao locality] form a small inlier in the steep hill-side which rises to the north of Pupiao plain, a small valley filled with lacustine deposits of late Tertiary age, drained by a stream flowing north-west to join the Salween, which is only 10 miles away to the west in a straight line. At the top they are covered with limestones, which are probably of Carboniferous age, while before the bottom of the hill is reached, they are buried by the tuffs which, with associated contemporaneous lava flows, shales and limestones of Carboniferous age, build up the western end of the

valley. The whole exposure is not much more than one half mile wide" (C. Brown. 3, p. 328).

The fossils are distributed in several minor horizons, as follows:

(1) Reddish-yellow soft and occasionally sandy shales.
(2) Hard nodular limestones with shaly laminæ.
(3) Very fossiliferous, fine-grained greenish-grey hardened shales.
(4) Rocks of the same character, further down the hill.

The more important species are the following:

GRAPTOLITÆ: *Didymograptus murchisoni* (Beck) (*3*, *5*) (Fig. 28b); *D. murchisoni* var. *geminus* (His.) (*3*, *5*); *Didymograptus indentus* (Hall) (*3*, *5*); *Climacograptus* cf. *scharenbergi* Lapw. (*3*). CYSTOIDEA: *Echinosphæra* cf. *aurantium* (Gill) (*5*); *Echinoencrinus* sp. (*1*, *3*, *4*); **Caryocrinus* cf. *turbo* Bather (*2*). BRYOZOA: *Pachydictya* sp., (*3*, *4*). BRACHIOPODA: *Orthis prætor* (Reed) (*1*, *3*, *4*, *5*) (Fig. 55). HYOLITHIDÆ: **Hyolithes* cf. *clivii* Reed (*3*); ***H.* cf. *loczyi* Reed (*3*), TRILOBITÆ: *Remopleurides* aff. *latus* Olin. (*3*); *Ogygites yunnanensis* Reed (*3*) (Fig. 56); *Illænus* cf. *esmarki* Schloth. (*3*); *I.* cf. *tauricornis* Kut. (*5*); *Nileus armadillo* Dalm. (*3*, *5*); *Bathyurus mansuyi* Reed (*4*); *Lichas* (*Metopolichas*) aff. *verrucosus* Eichw. (*4*); *Calymene unicornis* Reed (*3*); *Pliomera martellii* Reed (*1*, *4*, *5*).

Fig. 52.
Ovocystis mansuyi Reed Shih-tien. Left side of a complete specimen, natural size. (After Reed.)

Besides these, there are undetermined species of cystoids, brachiopods, (*Orthis*, *Streptis*, *Porambonites*), pelecypods (*Ctenodonta*, *Conocardium*), gastropods (*Rhaphistoma*, *Cyrtolites*), cephalopods (*Orthoceras*), and ostracods (*Primitia*).

The fauna of the beds at La-meng occurs in dark red or purple massive calcareous mudstones with somewhat splintery fracture. None of the fossils are well preserved. They comprise cystoids

* Occurs also in Lower Naungkangyi beds of Burma.
** Occurs also in Upper Naungkangyi beds of Burma.
1-4=horizons thus numbered, 5=horizon indeterminate.

(*Heliocrinus* aff. *fiscella* Bather), brachiopods (*Plectambonites*, *Orthis*), bryozoa (*Pachydictya?*), *Orthoceras* and trilobites (*Harpes* aff. *spasski* Eichw., *Ogygites?*).

Fig. 53.
Echinosphæra sinensis Reed. Shih-tien. a, anterior view of upper part with remainder restored ⅘ natural size; b, posterior side of adoral pole of same specimen showing plates; ×⅘, (*a*=anus; *h*=hydropore.)

At Shih-tien, the strata "crop out on a hill side to the west of the alluvium-filled valley, which forms the small Chinese district of Shih-tien (施甸) a few miles to the south of Yung Ch'ang Fu (永昌府) and west of the Salween. On the west they appear to be overlain by the older Palæozoic metamorphosed limestones, identical in appearance with the Plateau Limestone of the Northern Shan States. Towards the east they are covered by the alluvial deposits of the plain", (J. C. Brown 3 p. 331).

The succession of strata determined in this region by Brown is as follows, in descending order, commencing at an elevation of 6,700 feet.

1. Hard light gray limestone, apparently unfossiliferous.
2. Red earthy limestones and dark shaley limestones, including a species of *Illænus* and cephalopods (*Endoceras*, *Orthoceras*, *Cyrtoceras*, *Spyroceras?*).
3. Black fissile shales, faulted into the series and abounding in Silurian graptolites (See Chapt. V).
4. About 10 feet of greenish gray nodular marls, containing *Orthoceras* and crinoid (?) stems.
5. A series about 260 feet in thickness. Red marls with a roughened nodular surface, containing

Fig. 54.
Heliocrinus fiscella Bather. Anterior face of specimen, nat. size. (*a*=anus; *g*=gonopore; *m*=mouth.) (After Reed.)

Orthoceras and crinoid stems with intercalated greenish shales and lenticular limestones with many fossils.

6. Black massive shales with layers of concretions, exposed for a thickness of about 60 feet. Below these beds only poor exposures of weathered igneous rock were found for the next 200 feet, after which occurred scattered exposures of shales with Silurian graptolites, evidently displaced.

The following species have been found in these beds:

CYSTOIDEA: *Sinocystis loczyi* Reed (*5a*) (Fig. 51); *S. yunnanensis* Reed (*5a*); *Ovocystis mansuyi* Reed (*5*, *5a*) (Fig. 52); *Pyrocystis? orientalis* Reed (*2*, *5*); *Eucystis* cf. *raripunctata* (Ang.) (*5a*); *Echinosphæra asiatica* Reed (*5a*); *E. sinensis* Reed (*5a*) (Fig. 53); *Sphæronis lobiferus* Reed (*5*, *5a*); *S. shihtiensis* Reed (*5*, *5a*); **Heliocrinus fiscella* Bather (*5*, *5a*) (Fig. 54); **H. qualus* Bather (*5a*); *H. subovalis* Reed (*5a*); *H.* cf. *balticus* Eichw. (*5a*); *Caryocystis bicompressa* Reed (*5*). CRINOIDEA: ***Camarocrinus asiaticus* Reed (*5a*). BRACHIOPODA: *Philhedra sinensis* Reed (*6*); *Hemipronites giraldi* (Martelli) var. *yunnanensis* Reed (*6*); *Orthis prætor* Reed. (*6*) (Fig. 55); *Rafinesquina* sp. (*5a*). TRILOBITÆ: *Asaphus* aff. *expansus* (Linn.) (*6*); *Illænus cæcoides* Reed (*5*) (Fig. 57); *I.* aff. *oblongatus* Ang. (*5a*); *I.* aff. *schmidti* Nieszk. (*6*); *I.* aff. *punctulosus* Salt. (*2*); *Lichas* (*Metopolichas*) *celorhin* (Ang.) cf. var. *coniceps* H. v. Leucht (*6*); *Calymene* sp. (*5a*). GASTROPODA: *Halopea* (*Haplospira?*) sp. (*5*); *Bellerophon* (*Sinuites*) cf. *rugulosus* Koken (*5*). CEPHALOPODA: *Endoceras wahlenbergi* Foord (*5a*); *E.* cf. *cancellatum* (Eichw.) (*5a*); *E.* aff. *reinhardi* (Boll.) (*2*); *Orthoceras regulare* Schl. (*2*, *5*) (Fig. 58); *Orthoceras* cf. *kinnekullense* (Foord) (*5*); *O.* cf. *scabridum* (Ang.) (*2*); *O.* (*Protocycloceras?*) *deprati* Reed (*6*); *Actinoceras* cf. *bigsbyi* Bronn (*5a*); *Jovellania* sp. (*6*); *Cameroceras?* sp. (*5a*); *Cyrtoceras* sp. (*2*); *Spyroceras?* sp. (*2*); *Trocholites yunnanensis*

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*Also found in Lower Naungkangyi beds of Burma

**Also found in Nyaungbaw limestone of Burma.

1–6—horizons as listed; *5a*, weathered outcrops of various beds on lower slopes of hill.

Reed (*5*); *T.* aff. *macromphalus* (Schröd.) (*5*); *Lituites* sp. (*5*); *Tarphyceras?* sp. (*5*).

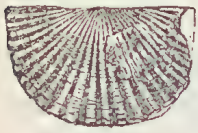

Fig. 55.
Orthis prætor Reed. Pedicle valve × 4. Shih-tien. (After Reed).

The most characteristic and abundant fossil in the collection from Pu-piao is *Ogygites yunnanensis* (Fig. 56). *Didymograptus murchisoni* (Fig. 28b.) and its variety *geminus*, appear to be next in abundance, while *Orthis prætor* (Fig. 55), appears to take third place. The graptolites indicate that the horizon of this fauna is the *D. murchisoni* (*D. geminus*) zone of the Llandeilo of Great Britain, while the other fossils indicate the Orthoceras limestone of Sweden, or the zones BIII–CI of the Baltic Provinces of Russia, or in general upper Llandeilan.* There is scarcely any trace of an American element in this fauna, though the trilobite *Bathyurus*, and the species of *Ctenodonta* and *Cyrtolitina* might suggest such. No relationship exist with the north China Ordovician faunas.

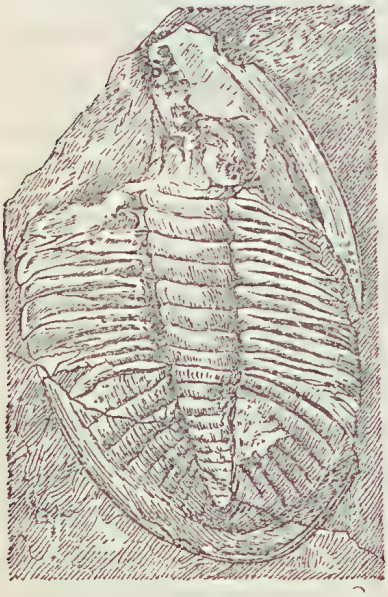

Fig. 56.
Ogygites ynnnanensis Reed; nearly complete specimen, slightly distorted. ×1½. Pu-piao (After Reed).

There seems to be only the scantiest relationship between this fauna and that of the Naungkangyi and Hwe Mawng beds of the Northern Shan States of Burma, though *Orthis prætor* appears to be represented in Burma by *O. irravadica*, and *Ogygites yunnanensis* by *O. birmanica*. They cannot represent the same horizon, and it may be that these beds belong above the Lower, and below the Upper Naungkangyi beds or they may belong below the Lower bed.

*For the relationships of the several European divisions see Grabau, 10.

As already noted, the Lameng beds are probably of the same age as those from Pu-piao.

Fig. 57.
Illænus cæcoides Reed; natural size. Shih-tien. (After Reed).

The fauna of the Shih-tien beds appears to represent essentially a unit. The most abundant species are the cystoids *Sinocystis loczyi* (Fig. 51), and *Ovocystis mansuyi* (Fig. 52), while the abundance of cephalopods, especially *Orthoceras regulare* (Fig. 58) is also striking. The horizon is probably that of the upper Orthoceras limestone of Sweden but may represent the lower Chasmops beds of that section, or C I γ of the Baltic provinces of Russia, as is also suggested by the abundance of cystidians and especially the presence of *Echinosphæra* (Fig. 53) among these. It is probable that these beds are slightly higher than those of Pu-piao. They may be the equivalent of the Upper Naungkangyi beds of Burma while the horizon from which *Camarocrius asiaticus* was obtained may represent that of the Nyaungbaw limestone of Burma in which that species also occurs. From the general similarity of the fauna of the Lunshan limestone of Nanking, this appears to represent the same general horizon as the Shih-tien beds of west Yunnan.

Fig. 58.
Orthoceras regulare (Schloth). Internal filling with shell removed showing septal edges, and cross section showing position of siphuncle; natural size. Shih tien, (After Reed.)

No Ordovician strata are known from eastern Yunnan; those formerly described as of this age are now known to belong to younger horizons.

Indo-China. Closely related to the Ordovician of Yunnan, and geographically forming a portion of these deposits, are the Ordovician beds of Indo-China. So far, Ordovician faunas are only known from Tonking and from Annam, a number of those previously described from other section were based upon material of foreign origin, or were erroneously placed in the Ordovician. The revised lists of these fossils are given by Mansuy (20, 22, Bibliography V).

In Tonking, Ordovician faunas are actually known to occur in two localities only. These are in the shales of Nam-ho, in the Pho-binh-gia quadrangle, and in those of Nga-hai, in the Thanh-ba quadrangle. From the former locality only two species have been obtained, a trilobite, *Calymmene douvillii* Mans., which occurs in great abundance and is closely related to *C. nivalis* Salter from the Himalayan Ordovician, and a brachiopod which appears to be identical with *Rafinesquina umbrella* Salter, which is also a typical species of the Himalayan Ordovician. The Nga-hai shales of Thanh-ba quadrangle, have also furnished two species of brachiopods, namely *Orthis budleighensis* Dav., a characteristic species of the late Middle and early Upper Ordovician of Normandy (Grès de May) of Spain etc., and *Strophomena expansa* Sowerby, a Caradocian and lower Llandovery (Silurian) species. These species suggest an Upper Ordovician age for the Tonking strata.

The Ordovician formations of Annam comprise the Asaphus sandstones of Dong-son, 4 kilometers N. N. E. of Thanh-hoa, north east Annam, a short distance south of the Tonking border. The fauna is rich in trilobites, among which new forms of Asaphidæ predominate. Those identified from this horizon are; *Ogygites* (?) *annamensis* Mans., *Asaphopsis jacobi* Mans. (gen. et sp.), *A. reedi* Mans., *Isotelus stenocephalus* Mans., *Prosopiscus cheiruroides* Mans., *Annamitella asiatica* Mans. (gen. & sp.). Of these only the genus *Prosopiscus* Salter, is represented by a distinct species in the Ordovician

of the Himalayas. A pelecypod (*Cypricardinia prisca* Mans.) and three species of *Orthis* (*O.* cf. *retrostriata* McCoy, *O.* cf. *hirmantensis* McCoy, and *O. testudinaria* Dalm.), and a cystid doubtfully referred to *Heliocrinus?*, complete the fauna. The brachiopods and trilobites suggest Upper Ordovician, which, like that of the Himalaya region, is localized.

The Ts'ingling Geosyncline. A series of folded Palæozoic and older rocks is seen to extend with a general east west direction across southern Kansu, parts of northern Szechuan, and southern Shensi, and to extend into north-western Honan and western Hupeh provinces to the north of the Yangtze River. Although they lie to

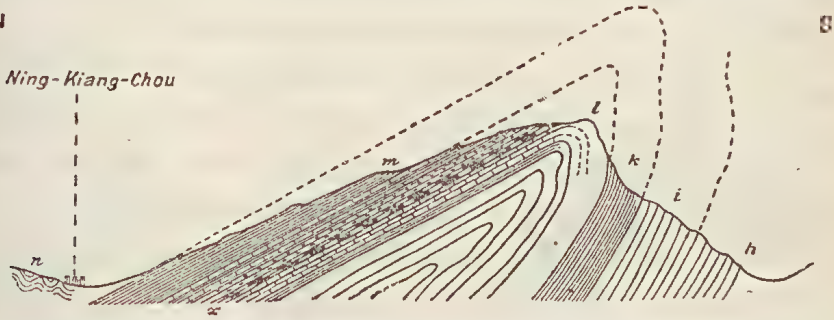

Fig. 59. Section of the overturned anticline of the Tshau-pi-shan, south of Ninkiang in southern Shensi, Tsingling range; (after von Richthofen); l, Upper Ordovician limestone shale and conglomerate; *k*, *m*, late Ordovician or early Silurian shales; *i*, *h*, Silurian (Niagaran) shales and limestones; *x*, lydianite conglomerate and lydianite.

the south of the main range of the Tsinglingshan, which rises to elevations of from 6,000 to 10,000 feet, they must be regarded as a part of the rocks of that range, folded and disturbed when they were folded, and in part at least of the same geological age. Only along the northern slopes of the Tsinglingshan are the older-Palæozoic rocks of the region shown today, while the rocks of the main range are metamorphosed Palæozoics and early Mesozoics, altered and hardened by granites and basic igneous rocks, which were intruded into them, most probably during the period of folding in Mesozoic time. There was however an earlier period of disturbance, the greater

portion of the Palæozoic rocks having been folded once before during the closing stages of the Palæozoic era.

We find the older Palæozoic strata exposed in the centers of the anticlinal folds in these southern foot-hills of the Tsinglingshan. These folds are overturned towards the south, so that the order of succession of the strata on the south side is reversed, the younger strata lying below the older. The section on page 89 (Fig. 59) after von Richthofen, shows such a folded series forming the Tshau-pi-shan ridge south of Ningkiang in south-west Shensi. In the center of this anticline, opened to view by erosion, we find the Ordovician strata, but only the higher members of these are visible. This ridge extends west south-west into the northern projection of Szechuan, and along its extent, von Richthofen collected a series of fossils which were described by Kayser (23). From the lower members of the series he obtained *Orthis kiautshangpensis* Kayser, and *Trinucleus richthofeni* Kayser (Fig. 60) and from higher beds *Orthis calligramma* Dalm. (Fig. 67), *Plectambonites sericeus* Sow. and other brachiopods, including a *Spirifer* which appears to be close to the Silurian *S. radiatus*. This leads to the conclusion that the beds exposed here, represent the uppermost Ordovician.

Fig. 60. *Trinucleus richthofeni* K. cephalon, enlarged.

Further east, in the border region of the provinces of Shensi, Szechuan, and Hupeh (Long. 109°30′—110° E., Lat. 31°30′—32° N.) a good exposure of the Ordovician beds has been found in the Ki-sing-ling Pass across the Kiu-Sung-shan, along the Ta-ning-ho. This has been described in some detail by Willis and Blackwelder. The same rock series is also exposed in the Wushan gorge of the Yangtze (Long. 110° E.) and in the gorges above Ichang. (abt. Long. 111° E.) In the latter region the base of the series is seen resting upon the older rock, and begins with the Nantou tillite already described,

(p. 19). The succession of formations as determined by Willis and Blackwelder, is shown in the following columnar section (Fig. 61) and the attitude of the strata in the sections Figs. 62 and 63:

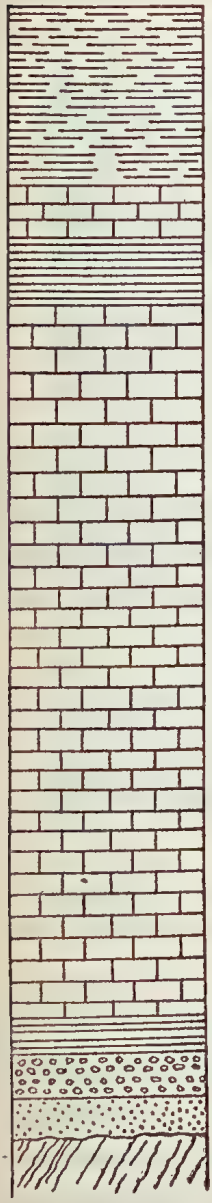

Fig. 61.

Columnar section in the Yangtze Canyon above Ichang, (compare Fig. 5). *a*, Huangling gneiss; *b*, conglomerate and arkoses; *c*, Nantou tillite (*b.c.* Sinian); *d*, Cambrian? shale; *e*, Kisingling limestone (Cambro-Ordovician) 1,000 meters; *f*, Nei-chia-shan? shales; *g*, Sükiapa formation (*f.g.* Upper Ordovician, 150 meters) *h*, Sint'an shale (post-Ordovician). Modified after Willis and Blackwelder).

The Kisingling Limestone. (Fig. 61e). This name was applied by Willis and Blackwelder to the Cambro-Ordovician limestones which succeed the Nantou tillite and overlying shales, in the Yangtze gorges above Ichang, and which are also exposed on the Taning-ho in Kisingling pass, whence the name is derived. The lower strata are thin-bedded limestone in layers from 10 centimeters to a meter in thickness, and range in color from dark bluish gray to liver brown. The upper three-fourths are almost devoid of flints. In the lower part of the limestone, Middle Cambrian fossils have been found, but whether the Cambrian portion of the limestone is distinct and separated from the Ordovician by a recognizable plane, or by a hiatus, is not known. Sections of *Orthoceras* have been found in the limestone but no distinctive fossils, to indicate whether any part is Lower Ordovician or not. Judging from the great thickness

of the series, one would be inclined to regard a part of the limestone as of Lower Ordovician age.

At certain levels, these limestones abound in the large and characteristic cephalopod *Orthoceras chinensis* Foord (Fig. 64) which

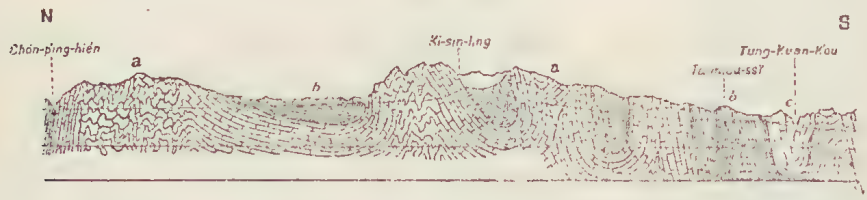

Fig. 62. Section along the Taning-ho, from Chön-P'ing-Hsien in southern Shensi to Tung-Kuan-Kou in northern Szechuan. (After Willis and Blackwelder) *a*, Kisingling limestone (Ordovician); *b*, Sint'an shale (post Ordovician); *c*, Wushan limestone (Carboniferous.)

may reach a length of several feet. Longitudinal sections of this fossil have a striking appearance, and the rock in which these shells occur, is cut into slabs, and the surfaces on which the shell section is exposed is polished. Such slabs are sold in China under the name

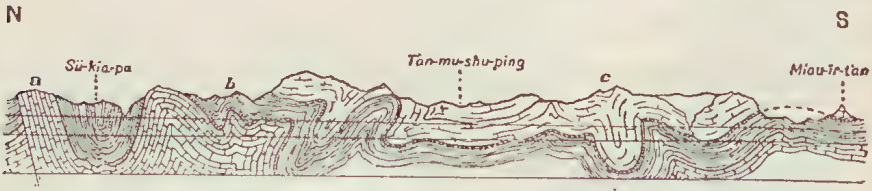

Fig. 63. Section along the Taning-ho from Sü-Kia-Pa to Miau-Ir-T'an in northern Szechuan. (After Willis and Blackwelder) *a*, Kisingling limestone (Ordovician); *b*, Sint'an shale (post-Ordovician); *c*, Wushan limestone—Carboniferous.

"Pagoda stone" and used for ornamental purposes. The age of the strata with *O. chinensis* was formerly held to be Devonian, but is now known to be Middle Ordovician. In Hsing-shan-hsien (Pan-tse-ya, Hu-hsi) in western Hupeh, a specimen of *Actinoceras* has also been found in this limestone, showing that in this region the northern and southern provinces had become confluent. In some sections, this limestone is often largely composed of a lime-secreting alga *Girvanella*

sinensis Yabe, which has much the appearance of huge, more or less compressed oval or ellipsoidal oölite grains, ranging in diameter from 4 to 7 mm. or more. In some cases this organism seems to have been the chief limestone former of this period. The same species is again found in the Lunshan limestone.

Fig. 64.
Orthoceras chinensis (Foord) longitudinal section.

The Neichiashan formation. The Kisingling limestone is succeeded by a series of shales with thin-bedded limestone beds, which are often richly fossiliferous. They are typically exposed in Nei-chia-shan and Pei-chia-shan, two hills near Hsia-T'an, not far from Ichang in Hupeh, (section Fig. 65; see also Fig. 61, beds f-g.).* These beds are exposed at a number of other localities in Hupeh, and from them Frech, and Yabe and Hayasaka described a number of fossils. They are shown in the section along the Taning-ho near Sü-kia-pa (see section Fig. 63), where their fossils were collected

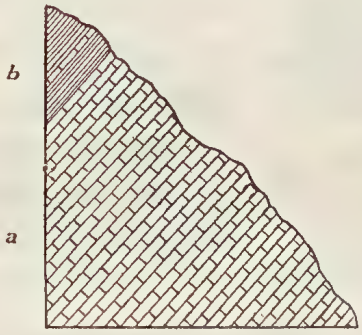

Fig. 65.
Section of Nei-chia-shan in Hupeh; *a*, Kisingling limestone; *b*, Neichia-shan formation.

*The survey has obtained a large collection of fossils from these localities through the good offices of H. B. M. Consul J. L. Smith, formerly of Ichang. These will be described and illustrated in the Palæontologia Sinica, Series B. Vol. I. fascicle 3.

by Blackwelder and described by Weller (36). They were again obtained in Lean-shan and elsewhere in the southern Tsingling-shan

Fig. 66. *Triplecia poloi* (Martelli), Hupeh.

in Shensi, and described by Martelli (28) and Pellizzari (29). Throughout this region there appears to be close agreement in the faunas of these beds, the leading species in Shensi being indentical with those most common in Hupeh. The overlying Sintan shale is, in part at least, of Silurian age.

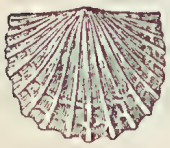

Fig. 67. *Orthis calligramma.* Dalm., Shensi.

Most abundant among the fossils of this formation are the brachiopods, with *Triplecia poloi* (Martelli) (Fig. 66) as the leading type. *Orthis calligramma* (Fig. 67) is also common, and some other species of this group also occur. The genus *Clitambonites* is well represented in all the faunas, there being apparently two or three species (Fig. 68). Gastropods are

Fig. 68. *Clitambonites giraldii.* (Martelli), Hupeh.

Fig. 69. *Eccyliopteris sinensis* Erech.

common, but there are only a few types. The most abundantly represented species is *Eccyliopteris sinensis* Frech (Fig. 69), which is widely distributed in central China. Cephalopods are common in this fauna. Besides *Orthoceras chinensis* Foord (Fig. 64) and other

species of this genus, there are several species of the annulated *Cycloceras* (Fig. 70), while *Endoceras* (Fig. 71) and *Vaginoceras* are also well represented, but the species have not yet been differentiated. Curved forms (*Cyrtoceras* (*Meloceras*) *asiaticum* etc.) also occur, as well as coiled forms, the most conspicuous among which is *Discoceras eurasiaticum* Frech (Figs. 72a, b). Finally, trilobites form an important part of the fauna. The genus *Asaphus* is represented by half a dozen or more species (Fig. 73), and the related *Isotelus* by several more (Fig. 74). *Illænus* too, is represented by several species (Fig. 75). Other genera are *Calymmene*, *Pterygometopus?* *Ampyx* and *Megalaspis*.

Fig. 70.
Cycloceras sp.

The fossils of this fauna are among the best preserved in China, equalled only by those of the Devonian rocks. The brachiopods of these and the Devonian shales are commonly sold in the Chinese drug stores under the name of Sce-Yih or Stone Swallows (石燕), and various medicinal qualities are attributed to them.

These beds are the essential equivalents of the Actinoceras limestone of north China, though their fauna is so markedly distinct. Although containing many new species, the fauna is essentially a European type of fauna. The age of these beds is approximately that of the Orthoceras limestone of Sweden, and of the Vaginatenkalk of the Baltic provinces of Russia, and essentially that of the Black River formation of North America. Some of the beds of south-western Shensi may be of somewhat younger age representing the Upper Ordovician (Caradocian or Trentonian), and this is probably also the age of the higher Ordovician beds of western

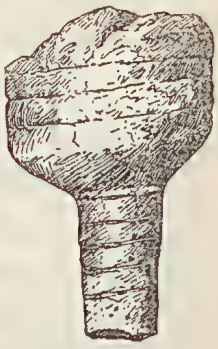

Fig. 71.
Endoceras sp. with part of "siphuncle" exposed.

Yunnan, and those of Indo-China.

The Lunshan Limestone. (Section Fig. 76.) In Lunshan and Tangshan, low hills near Nanking, in Kiangsu province, are found the eastern-most exposures of the Ordovician strata of central China. This LUNSHAN LIMESTONE as it has been called, rests apparently on granite, but that is really a late Palæozoic intrusive rock. Fossils are rare in this limestone, consisting chiefly of brachiopods, among which the genus *Clitambonites* (formerly called *Orthisina*) predominates. The common species has been referred to

Fig. 72a. *Discoceras eurasiaticum* Frech.

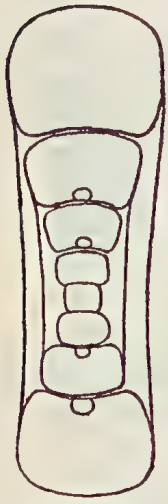

Fig. 72b. *Discoceras eurasiaticum* Frech (section).

C. squamata (v. Pahlen). Other brachiopods (*Orthis* cf. *calligramma* Dalm. Fig. 67); gastropods: (*Eccilioptcris sinensis* Frech, Fig. 69, etc.); and cephalopods: (*Endoceras duplex* Wahl. etc.), as well as trilobites of the group of *Asaphus expansus* have also been reported from this rock by Frech.

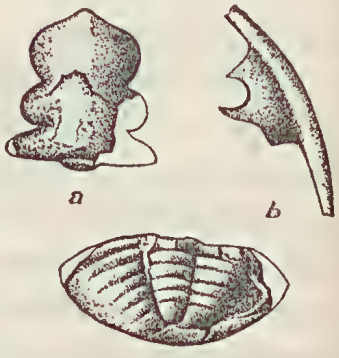

Fig. 73.
a,b. *Asaphus blackwelderi* Weller. ×2 ¾ c, *A.* cf. *expansus* ×2.2.

There are also some beds of limestone, which are entirely composed of the calcareous alga *Girvanella*

sinensis Yabe. This species was originally obtained from limestone of similar age in Hupeh province.

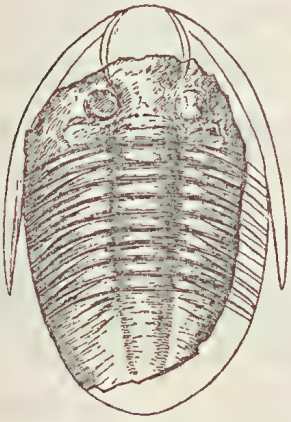

Fig. 74.
Isotelus usurii Yabe. Nei-chia-shan, Hupeh. (Partly restored).

Fig. 75.
Illænus sinensis Yabe, two views of enrolled specimen. Nei-chia-shan, Hupeh.

The Lunshan limestone is essentially the equivalent of the upper part of the Kisingling limestone, and perhaps in part of the Neichiashan formation. Its thickness is unknown, but considerable,

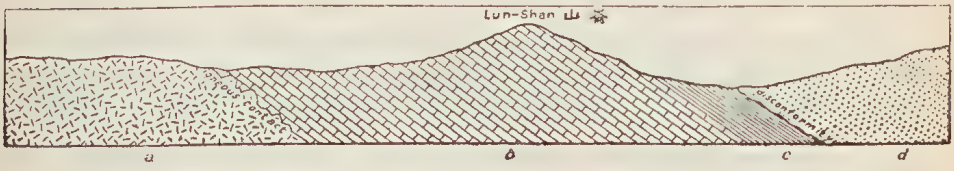

Fig. 76. Section of Lun-Shan, near Nanking. *a*, Intrusive granite; *b*, Lunshan limestone (early Upper Ordovician); *c*, Silurian graptolite shales; *d*, Wutungshan quartzite (Lower Carboniferous?).

and so far as known it is a unit. It is disconformably succeeded by Silurian (Niagaran) graptolite shales.

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CHAPTER V.

THE SILURIAN SYSTEM.

General Characters and Subdivisions.

When, at the close of the Ordovician period, the seas again withdrew from the continents which they had flooded with wide but shallow water-ways in late Ordovician time, they did so in obedience to a combination of forces, all of which tended to lead events more or less simultaneously in the same direction. Foremost among these was the steady rising of the primary land-masses, especially Appalachia, Atlantica and Cathaysia, those positive elements of the earth's crust which, throughout Palæozoic history, controlled the progress of development. In the geosyncline which bordered Appalachia on the west, the progressive rising of the old land culminated in a deformative movement, which folded the older strata of the geosyncline, producing the ancient Taconic range of mountains of new England. A similar disturbance is shown to have occurred in the Baltic geosyncline, by the unconformable superposition of the Silurian upon the older Ordovician beds in some parts of England. There is at present no evidence to show that similar deformative movements affected the Chinese region, for, wherever known, the Silurian strata of China rest without unconformity, though with a disconformity and hiatus, upon the late Middle or early Upper Ordovician beds.

Before the folding of the American Ordovician strata began, the rising old-land of Appalachia effected the rejuvenation of the streams. This resulted in the carrying of extensive masses of clastic material into the waters of the epicontinental seas, the borders of which were progressively pushed back, and the seas themselves

replaced to a considerable extent by broad stretches of alluvial plains. In this manner was formed the great series of continental beds, often red, which closed the Ordovician sedimentation in eastern North America, and which has some analogues in the corresponding beds of other countries. But in addition to the rising of the lands and the spreading of continental sands, there was probably a general deepening of the ocean basins, and this was perhaps the main cause which effected the withdrawal of the waters from the geosynclines and epeiric seas. For this withdrawal was, according to all appearances, a simultaneous one,—was one of the major eustatic movements of the sea, though a negative one, and such a movement could hardly be produced by any other cause.

We find then, at the opening of Silurian time, that the continents of the earth had again assumed their extended outlines, which, at that time, were much greater than they are today, for Appalachia, Atlantica and Cathaysia occupied portions of the present oceanic areas. The southern continents were probably also more extended, though of this we know very little. The three main oceans of the Palæozoic, the Boreal, the Atlantic, and the Pacific (with which was apparently conjoined the Indian), had again become separated, much as they were in early Ordovician time. There is every reason for believing that the Boreal was the ocean of abundant life, and that this life was tropical in character, because the waters then were warm. For this was the center of coral life, and from it proceeded the various migrations which peopled the epeiric seas with reef-building corals, when such epeiric seas had again come into existence. Moreover, we are forced to conclude that the Boreal realm was the center of origin, as well as distribution, of the great host of coral polyps which, in Silurian as well as in Devonian time, became the chief limestone formers of the earth; for in this direction all the known evidence points unmistakably. Coral-building polyps, except the *Archæocya-*

thinæ, were not abundant in early Ordovician time, though in the latter part of the period certain forms such as *Tetradium* became of importance. In the place of the corals, flourished the coralline Bryozoa, which, with the lime-secreting algæ, were the chief limestone builders. But towards the close of Ordovician time true coral polyps had become a marked element of the fauna, for we find that in some regions the invading waters, in late Upper Ordovician (Richmond) time, were already peopled to some extent with the coral elements which became so prominent in Silurian time.

The Silurian corals included all of the major groups of Palæozoic corals known. The tetraseptate corals were represented by both simple and compound forms. The simple forms comprised the *Streptelasmoid* types, which had already become a marked feature of the Ordovician fauna, a number of cyathophylloids, and primitive zaphrentoids and cystiphylloids, and the rather specialized *Omphyma*, *Chonophyllum*, *Rhizophyllum* and *Goniophyllum*. Among the compound forms, *Acervularia*, *Stauria*, *Diphyphyllum* and *Eridophyllum* predominated. The aseptate types were chiefly represented by *Favosites*, *Alveolites*, *Syringopora*, and especially by *Halysites*. Of other types, the genus *Heliolites* should be especially noted as abundantly represented and widely distributed. In addition to these true corals, there were many genera and species of the hydrocoralline stromatoporoids.

Other distinctive elements of the Boreal fauna are found among the cephalopods, especially the *Orthoceran* types, while *Actinoceras* still continued with almost unabated vigor. Peculiar cephalopods with contracted apertures (*Gomphoceran* types) also became very characteristic, though these may have had an Atlantic origin. Finally, it is highly probable, that a large part of the crinoid element found in the Silurian fauna originated in the Boreal sea.

Apparently the Atlantic basin was still the home of grapto-

lites, for we find their remains primarily associated with those of other organisms known to have been more or less restricted to this basin. But the older types of graptolites had largely disappeared, and in their stead, stipes with a single row of tooth-like cups, the *Monograptidæ*, had become the leading types. That they still belonged to the floating or planktonic biota, is suggested by the mode of their occurrence, as well as by their wide distribution. Hence, as in Ordovician time, the graptolites still form excellent index fossils for the correlation of formations at widely distant localities.

The brachiopod element of the Atlantic too, was a distinctive one, though in how far it was endemic there, is not an easy matter to determine. Some, at least, of the types which appear to be characteristic of that basin, may have originated in the Boreal realm, though they became much modified in these waters. One of the forms of this fauna was the smooth *Pentamerus oblongus*, while among the plicated shells was the small *Cœlospira hemisphærica* and the large *Stricklandinia*. *Plectambonites* and *Chonetes* also seem to have been members of this fauna.

Probably the purest development of this fauna is seen in England, though even here there is an admixture of boreal types which arrived by way of Scandinavia. On the American side of the Atlantic, the fauna of this province is seen in its greatest purity in the rocks of the Island of Anticosti in the St. Lawrence Gulf. It entered the interior of North America as the Clinton fauna. The Bohemian development must probably be regarded as a localized phase of the Atlantic Silurian, developed under special conditions of partial isolation.

The northern fauna is best known from the interior North American region, where in Michigan, Wisconsin, Ohio and Kentucky, it has its elements least intermingled with those of other provinces. On the European side, the Gotland development must probably be

considered as the one least modified by Atlantic immigrants. It was however a commingled Atlantic and Boreal fauna which migrated across Europe and Asia into the Chinese basin. With it there may have been a certain commingling of Pacific types from the Indian embayment. We know the general characters of the fauna of the Pacific province from deposits formed in embayments of that ocean in southern North America, before there was any opportunity for the commingling with faunas of other provinces. Such an embaymen occurred at the beginning of Silurian time, and again during the early part of the Upper Silurian (Monroan). During other epochs of the Silurian these embayments, though continuing, became confluent with the waters which extended from the Boreal province, as well a those from the Atlantic province, so that a certain commingling, or at any rate alternation of faunas occurred in the region of such confluence. Nevertheless it is possible even then, to evaluate the faunas and to separate out the essentially Pacific types.

These known Pacific types are remarkable for their general depauperate aspect. As a rule the individuals are small, and the number of species appears to be limited. Among the brachiopods, small plicated or nearly smooth *Spirifers*, small *Rhynchonelloids*, and *Retzioid* types, smooth *Whitfieldellas* and small *Strophomenoid* types predominate. The pelecypods too, are few and small, though numerous in individuals; cephalopods are rare or absent, and corals are practically unknown. *Tentaculites* and ostracods seem to have constituted the leading elements of the plankton, and are often found in enormous numbers. Altogether the fauna exhibits a striking contrast to that of the Boreal and Atlantic provinces, and suggests unfavorable conditions of existence. The suggestion presents itself that the region from which the known part of this fauna was derived was one of cold waters. If this were the case, it would be of great significance, when we consider that the north polar region of today was a warm water

region, with coral reefs in Silurian time. A plausible explanation of this inversion of climatic conditions seems to be the former different position of the earth's mass with reference to its axis. If the present north polar region was tropical in Silurian time, a part of the present tropical region of the Pacific may have been one of the polar regions of the past, while the other was in the region of the Indian ocean. On such a supposition one could perhaps explain the depauperate character of the Silurian fauna of the eastern Pacific region as well as that of the Indian Ocean.

If we now contemplate the major events of the Silurian period as determined from the sediments and their faunas, we find that throughout Lower Silurian time, the movement of the seas was a transgressive one, punctuated, however, at intervals, by periods of rest or even temporary withdrawal. In the beginning, clastic sediments were still forming along the borders of the main land masses, but as the transgression of the seas continued, these clastic deposits gave way to organically formed rocks, and limestones became the dominant type of deposit, though of course, near the shores, muds and even some sands continued to accumulate. With the attainment of the maximum in sea transgression, the Boreal fauna spread far and wide, its corals occurring in the majority of sediments of this period. It was then, that the Silurian coral fauna entered into the Chinese basin by way of the Himalayan geosyncline. Towards the end of Lower Silurian time the seas again withdrew from the lands, and as the evidence for such withdrawal is now well nigh universal, we may consider this one of the great negative eustatic movements which affected alike all the lands. It is a remarkable fact that up to the present time, no marine Middle Silurian strata have been found anywhere. Those that have heretofore been considered to represent Mid-Silurian time, have proved on closer examination to belong either to the Lower or to the Upper Silurian. In all sections where the Silurian strata have been closely

studied, the Lower and Upper Silurian strata are separated by a hiatus and disconformity. In a few cases only, is the interval represented, in part at least, by continental sediments; for the most part, when both Lower and Upper Silurian are present, they are separated by an erosion interval.

That this erosion interval was a long one, fully long enough to represent the whole of Mid-Silurian time, is shown by the fact that, where it is replaced by continental sediments in eastern North America, these sediments, which constitute the Salina formation, are accompanied by extensive salt deposits. From their characteristics, these salts must be regarded as desert salts, formed in enclosed basins not in connection with the sea, but essentially after the manner of the salt deposits formed in the interior deserts of Asia today. From their extent and thickness it is evident, that the time required for their formation was very great, for such accumulations proceed at a relatively slow rate.*

On parts of the Island of Gotland, in the Baltic, the Lower and Upper Silurian (Lower and Upper Gotlandian), are likewise separated by a continental formation, the Burgsvick or Gansvick sandstone. But this is of only moderate areal extent and of slight thickness, and does not represent continuous deposition during Mid-Silurian time. Elsewhere on the island the Lower and Upper Gotlandian series are separated by an erosion plane. (Grabau 4)

Upper Silurian time was again marked by a re-advance of the seas and the renewal of marine deposition. The fauna of the Boreal province had become considerably modified during Middle Silurian time, so that on its return to the epeiric basins of the continents, it presented mostly new species if not new genera. This modification was most pronounced in the coral and stromatopora

*For a full discussion of this problem see Grabau 3.

elements of the fauna, though some of the older types, such as *Halysites*, still held on, probably because it had become an inmate of the larger Atlantic basin, where modification was progressing less rapidly. In the Pacific basin too, the fauna, on the whole, remained of the same general type, though species and even some of the genera were undergoing modification. Nevertheless, the Pacific fauna retained its diminutive and depauperate character, and where it occurs uncontaminated by other faunas, it is readily recognized.

The newer classification of the Silurian formations is based upon the recognition of this three-fold character of the system: a lower marine, a middle non-marine and an upper marine division. The smaller divisions recognized in North America are as follows, these being primarily based upon changes in lithic character and dominance of one or the other of the three faunas which had access to the interior North American waters.

North American Subdivisions of the Silurian:

Upper Silurian or Monroan (chiefly marine).

Upper Monroan or Detroit River Series.
Sylvania sandstone (non-marine).
Lower Monroan or Bass Island Series.

Middle Silurian or Salinan (non marine).

Salina red-beds, and salt deposits with secondary gypsum.

Lower Silurian or Niagaran (chiefly marine).

Guelph dolomite and Shawangunk conglomerate (fluviatile).
Lockport limestones.
Rochester shales.
Clinton limestones.
Medina series (partly fluviatile).
The Medina series is restricted to the marginal portion of

Appalachia, and is chiefly a sandstone or fine conglomerate formed as a series of alluvial fans along the borders of the Appalachian old-land (Tuscarora, Clinch, etc.). Remains of Eurypterids are sometimes found in these beds, for these animals formed the principal life of the rivers of the period. Away from Appalachia, these beds are represented by normal marine sediments, which in some parts of the country carry the Pacific fauna, in others a modified Atlantic, and in still other sections the typical Boreal fauna. The Clinton is mainly differentiated on the basis of its Atlantic fauna (*Pentamerus oblongus*, *Monograptus*, etc.), which for a period extended far into the interior. Beyond the reach of this invasion the Boreal fauna occupies these beds also. The Rochester shales are a lithic unit with, however, a commingling to some extent of the faunas of the several provinces, but the Lockport in its purity heralds the dominance of the Boreal coral fauna. Finally, the Guelph marks the beginning of the withdrawal of the seas, and the Shawangunk conglomerate, its partial equivalent, marks the renewed elevation of Appalachia, and the rejuvenation of its streams. These too, carried Eurypterids and other fluviatile types, some of which became embedded in the finer sediments which formed the closing stages of the Guelph deposition (Pittsford shales).

The Salina is characterized by extensive alluvial fans in the Appalachian region; these deposits are now largely characterized by a red color, indicating arid conditions during their formation. Further inland, the strata become calcareous, being the redeposited lime-sands and muds which were formed in the first place by disintegration of the Niagaran and older limestones during the mid-Silurian interval of exposure. In certain sections these deposits enclose the rock-salt, and the limestones of this series are frequently altered to gypsum. No fossils are found in this series.

The Lower Monroe beds are at present known only from the southern half of North America but they cover an area of great extent.

They are wholly characterized by the depauperate fauna of the Pacific province, in an embayment of which they were deposited. As such they furnish us with the best criteria for the evaluation of this fauna, and this becomes significant from the fact that the known Upper Silurian fauna of China is essentially of the Pacific type. In American deposits of this age, small brachiopods and pelecypods are most common, and in some sections ostracods seem to be the leading faunal element. At the end of this period a withdrawal of the southern sea, and a local spreading of eolian sands, characterized this region (Sylvania sandstone), while from the Appalachian lands river deposits extended with the remains of Eurypterids and fishes. This was followed by a pronounced advance of the sea from the north in upper Monroan time bringing back the coral elements of the Silurian fauna, but in a much modified form. Indeed, many of these have characters known otherwise only among Devonian corals. The same is true for some of the brachiopods. As we shall see, an important element of the succeeding Devonian fauna was derived from this late Silurian fauna, the modification going on within the Boreal province, when that had again become isolated.

The southern or Pacific sea also advanced again in upper Monroan time, and the two faunas met, and to some extent became commingled. This commingling was not, however, very general, for we find in the upper Monroan of eastern North America (eastern New York region) an alternation of faunas. Thus the coral fauna of the Boreal realm dominated at one period (Cobleskill limestone stage) and the Pacific element at another (Manlius limestone stage). In addition to this, the Atlantic fauna had access to the Appalachian trough, greatly complicating the faunal aspect. As will be more fully shown later, the known Upper Silurian beds of China are wholly lacking in the northern element which was so prominent in Lower Silurian time. This has an important bearing on the palæogeography of China in late

Silurian time.

The Silurian succession in England, the birth-place of the "Silurian System", is usually taken as the standard for western Europe, and must serve to a certain extent as the standard for China as well. As however, the fauna of the British rocks, though primarily of the Atlantic type, is modified to a certain degree by the influx of the Boreal element by way of the Baltic, it partakes to a certain extent of a cosmopolitan character. Hence we can use the terms of larger divisions, derived from the more complete succession in North America, to include the special divisions based on the British succession. The classification then would be as follows:

Classification of Silurian Rocks of West Europe.

Upper Silurian or Monroan (Upper Gotlandian).

Downtonian series.

Downton sandstones, Ledbury shales etc. (continental).

Upper Ludlow shales etc.

Hiatus and disconformity.

Middle Silurian or Salinan (wanting).

Lower Silurian or Niagaran (Lower Gotlandian).

Salopian series.

Lower Ludlow and Aymestry.

Wenlock group:—shales and limestones.

Valentian series.

Llandovery shales, Mayhill sandstone, etc.

The Lower Silurian or Niagaran is most extensively developed in western Europe, though in the British region shales sandstones and even conglomerates predominate, forming a thick series of clastic rocks, in which organic remains are found often only at certain levels. In some sections only graptolites are found, these occurring after the

manner of those found in the Ordovician strata, and like them indicating sea-margin mud-flats and deltas, upon which these floating organisms were stranded during periods of high water. As was the case with the Ordovician graptolites, those of the Silurian form a succession of specific types, and because of their wide distribution they too form excellent index fossils even for China. The succession of graptolite zones determined for the clastic deposits of western Europe is as follows in descending order:

Graptolite Zones of the Silurian.

(Chiefly after Elles and Wood).

UPPER SILURIAN (no graptolite zones).

LOWER SILURIAN (Niagaran).

LOWER LUDLOW.

22 Zone of *Monograptus leintwardinensis.*

21 Zone of *Monograptus tumescens* (*M. chimæra, M. bohemicus*).

20 Zone of *M. scanicus* (*M. dubius, M. rœmeri, M. varians, M. chimæra, M. bohemicus*).

19 Zone of *M. nilsoni* (*M. dubius, M. colonus, M. rœmeri, M. varians, M. chimæra, M. uncinatus*).

18 Zone of *Monogratus vulgaris.*

WENLOCK.

17 Zone of *Cyrtograptus lundgreni* (*Monogr. vomerinus, M. dubius, M. flemingi, M. irfonensis* and *Cyrtograptus carruthersi*).

16 Zone of *Cyrtograptus rigidus.* (*Monogr. vomerinus, M. dubius, M. retroflexus, M. flemingii*).

15 Zone of *Cyrtograptus linnarssoni* (*Monogr. vomerinus, M. dubius, M. flexilis*).

14 Zone of *Cyrtograptus symmetricus* (*M. vomerinus, M. dubius.*

13 Zone of *Monograptus riccartonensis* (*M. vomerinus*, *M. capillaceus*, *Cyrtogr. flaccidus*).

12 Zone of *Cyrtograptus murchisoni* (*M. priodon*, *M. vomerinus*, *M. hisingeri*, *Retiolites geinitzianus*).

Tarannon Shales.

9 Zone of *Cyrtograptus grayæ* (with *Monogr. turriculus*, *M. hisingeri*, *M. becki* in southern region).

Zone of *Monograptus exiguus* (with *M. densus* and *Diplogr. palmeus* elsewhere).

Zone of *Rastrites maximus*.

Lower Llandovery.

Zone of *Monograptus gregarius*.

Zone of *Diplograptus vesiculosus*.

1 Zone *Diplograptus acuminatus*.

The lower zones are better represented in Scandinavia where we have below the zone of *Cyrtograptus murchisoni* (12) the following, according to A. Hennig:

11 Zone of *Cyrtograptus lapworthi*.

10 Zone of *Monograptus spiralis*.

9 Zone of *Cyrtograptus grayæ* (with *M. turriculus*, *M. hisingeri*, *M. becki* in Bohemian basin).

8 Zone of *Monograptus runcinatus*.

7 Zone of *Monograptus sedgwicki*.

6 Zone of *Diplograptus cometa*.

5 Zone of *Monograptus convolutus* (*M. lobiferus*, *Rastrites perigrinus*, *Climacogr. scalaris*, in Bohemian basin).

4 Zone of *Diplograptus folium*.

3 Zone of *Monograptus triangulatus*.

2 Zone of *Monograptus cyphus*.

1 Zone of *Diplograptus acuminatus*.

Silurian in Asia.

We may now briefly review the known occurrences of Silurian strata elsewhere in Asia, before turning specifically to those of China (Map, Fig. 77).

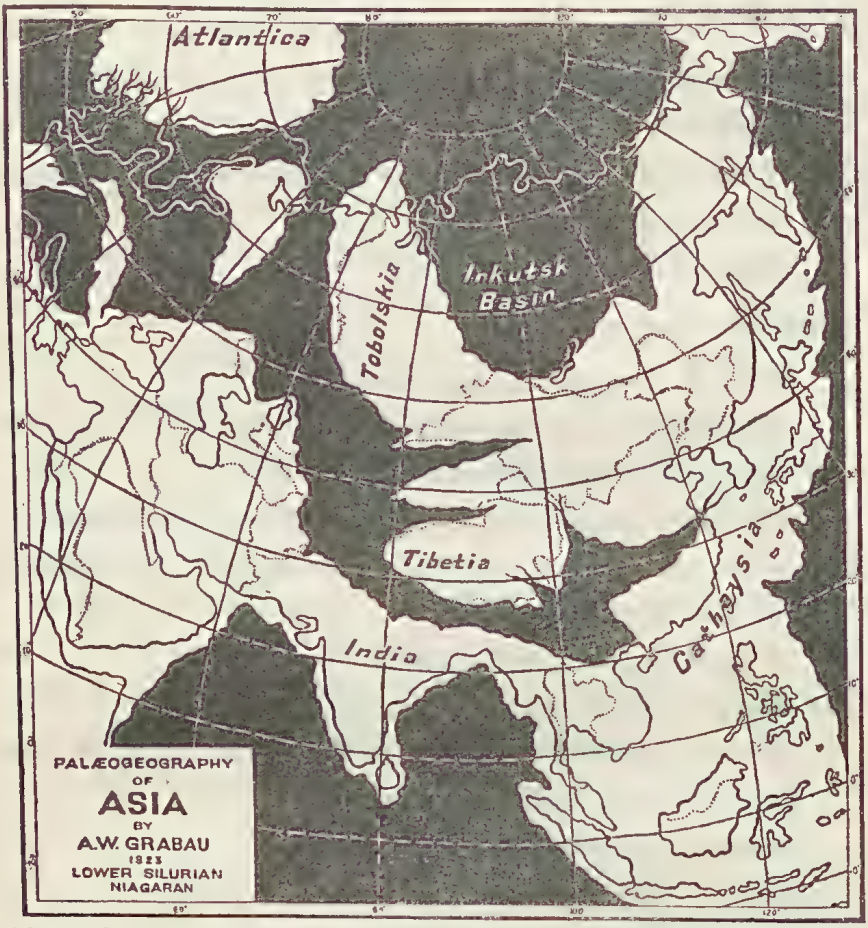


Fig. 77. Palæogeographic map of Asia, showing the probable distribution of land and water (black), in Lower Silurian (Niagaran) time. Graptolite shales were deposited at the mouths of the rivers indicated.

Siberia, etc. Silurian rocks are widespread in the Irkutsk basin of Siberia and they are wholly of the Boreal type. Indeed it is to this region that we must look for a full knowledge of the character of this fauna. It is known that corals are characteristic of these

strata, for they have been obtained by von Toll even in the New Siberian islands, and by others in many parts of the Irkutsk basin. The strata in the latter region are still largely horizontal, resting upon the Ordovician beds, and are covered by extensive basalt flows of younger age. From New Siberia von Toll has obtained the trilobites *Bronteus anderssoni* and *Phacops quadrilineata* and the corals *Halysites catenularius* and *Favosites gothlandicus* besides *Leperditia* and Foraminifera. Among the fossils found in the other region of the Irkutsk basin, those from the banks of the Podkamennaia Tunguska include the following species of corals identified by Lindström (7): *Favosites forbesi* E. & H.; *F. gotlandicus* L. (Fig. 86); *F. hisingeri* E. & H.; *F. asper* Goldf.; *F. lonsdalii* d'Orb.; *Halysites catenularius* L.; *Calopœcia cribriformis* Nichols.; *Columnaria alveolata* Goldf.; *Cyathophyllum articulatum* His.; *Zaphrentis conulus* Lindstr. The brachiopods *Atrypa duboisi* Vern. and the trilolites *Phacops* (*Monorakus*) *lopatini* Schm. and *P. sibiricus* Schm. have also been cited from these beds, while from other localities in the basin the brachiopods *Pentamerus oblongus*, *Leptocœlia duboisi* and *Strophomena euglypha*, and the trilobite *Phacops quadrilineatus* have been obtained. Some Silurian (Ludlow) fossils have been reported from Turkestan by Romanowski and from this region British Upper Ordovician (Bala) species are also recorded. Wenlock beds have recently been discovered in central Asia and near Lake Balkash in the Steppes of Asiatic Russia, by Edelstein (1) and Stepanov (27).

Himalayas. In Spiti and other regions of the Himalaya mountains, strata of Silurian age are said to rest conformably upon Ordovician formations. The succession in Spiti is as follows, according to Hayden (IV, 16) and Reed (IV, 31). In descending order:

9 White Muth quartzite passing gradually into

8 Reddish-brown quartzite, underlain by gray siliceous limestone, weathering red and pink (ab't. 80 ft.).

7 Gray limestone, weathering red and brown, with red and brown marls (ab't. 70 ft.).

6 Gray coral limestone (ab't. 50 ft.).

5 Ordovician shaly limestone.

The corals of horizon 6 include the genera *Favosites, Halysites Propora, Stylarea* etc. but the species are all distinctive. The succeeding limestone (horizon 7) contains mainly brachiopods, among which may be noted: *Orthis,* (*Dalmanella* and *Plectorthis*), *Leptæna rhomboidalis, Strophonella* and *Stropheodonta.* Finally in horizon 8, the characteristic *Pentamerus oblongus* and other typical European Lower Silurian species are found, including a few corals. Altogether the fauna, so far known, is a very early Silurian one, especially in the lower horizons, with many local modifications. In the higher horizons the European affinities become more marked. Similar Lower Silurian (Llandovery) beds have been described from Kashmir (Reed 24).

Burma. In the Northern Shan States of Burma, west of the Chinese border, Silurian strata are well developed and richly fossiliferous. The fossils have been described by Reed (IV, 30, 32)* and the stratigraphy by La Touche (IV, 25). The revised succession is as follows:

Zebingyi Stage

Namhsim Stage

Upper or Kônghsa Marls

Lower or Namhsim Sandstones

Panghsa-pye Stage

Upper of Graptolite Band

Lower or Trilobite Band

Sub-formation: Nyaungbaw limestone (Ordovician)

The Panghsa-pye beds. These are of Llandovery age and

*This refers to titles 30 and 32 in Bibliography IV, page 98.

extremely rich in organic remains (La Touche IV-25, pp. 125-129). The Lower or Trilobite Band contains all the fossils described, except the graptolites. The fossils consist chiefly of brachiopods and crustacea, the trilobites among the latter giving the name to the bed. The genus *Orthis* is well represented among the brachiopods by forms closely related to, if not identical with, typical Llandovery species of Europe, including the widespread *O.* (*Dalmanella*) *elegantula* (Dalm.). *Stropheodonta* is represented by two species, both new, but related to European forms and to those of the American Clinton type, which is the Atlantic fauna. *Schuchertella* is likewise represented by two species, one of them the widespread *S. pecten* (Linné), the other (*S. planissima*) related to both west European, and American early Silurian species, the latter of the Atlantic fauna. The trilobites are *Acidaspis shanensis* Reed and *Dalmanites hastingsi* Reed, both new species, but both allied to European forms. Finally, there are ostracods, referable to the genera *Bollia*, *Klædenella?*, and *Primitiella?*, all the species being new.

The upper or graptolite beds carry only graptolites, three horizons being represented, the lower two indicating Lower Llandovery, the third suggesting Wenlock age.

Horizon 1 is characterized by the abundance of Diplograptids, the species recorded being *Orthograptus vesiculosus* Nich.; *Mesograptus modestus* Lapw; *Climacograptus medius* Törnq.; *C. rectangularis* McCoy; *Dimorphograptus extenuatus* E. & W.; *Monograptus incommodus* Törnq.; *M. sandersoni* Lapw.; *M. cyphus* var. Lapw. Horizon 2 contains five species of *Monograptus* (*M. gregarius* Lapw.; *M. revolutus* Kurck; *M. atavus* Jones; *M. raitzhainiensis* Eisel.; *M. triangulatus* Hark.), together with *Mesograptus modestus* Lapw.; *M. magnus* J. & Lapw.; *Climacograptus tornquisti* E. & W.; *C. hughesi* Nich.; *C. rectangularis* McCoy; *Dimorphograptus extenuatus* E. & W.; and *Retiolites approximatus* var. *geinitzi* Törnq.

Horizon 3, the Kanlun beds, contains only *Monograptus priodon* Brown, and *Cyrtograptus* sp. both indicative of Wenlock age.

The Namhsim Stage. The Namhsim sandstone is a quartzitic or feldspatic sandstone with some conglomerate, and contains a fauna of brachiopods and trilobites. The facies, though predominantly European, has a few local elements, but very few species are common to it and the overlying Kônghsa marls. It is marked by the abundance of *Phacops longicaudatus* var. *orientalis*. Other trilobites found here are (1) *Calymmene blumenbachi* Brongn. var ; (2) *Cheirurus* cf. *bimucronatus* (Murch.) ; (3) *Encrinurus konghsaensis* Reed; (4) *Illænus namhsimensis* Reed; and species of (5) *Proetus*. Of brachiopods only (6) *Lindstrœmia* cf. *subduplicata* (McCoy) ; (7) *Mimulus aunglokensis* Reed and a species of *Orthis* are found. Pelecypods and an *Orthoceras* also occur.

The Upper Namhsim or *Kônghsa marls* carry a fauna suggestive to some extent of the Lower Ludlow. The leading trilobite is *Phacops shanensis* Reed ; species 1 to 3 of the preceding list also occur. Brachiopods are common, all of them being referable to European species. They comprise such characteristic species as *Leptæna rhomboidalis* Wilck. ; *Stropheodonta corrugatella* (Dalm) var. ; *Schuchertella pecten* (Linn.) ; *Dalmanella elegantula* (Dalm.) ; *Platystrophia biforata* (Schl.) ; *Pentamerus* cf. *oblongus* Sow. ; *Gypidula* cf. *galeata* (Dalm.) ; *Conchidium* cf. *biloculare* (Linn.) ; *Atrypa reticularis* Linn. ; *Glassia* cf. *compressa* (Sow.)? ; *Spirifer* cf. *radiatus* Sow. ; *S. sulcatus* His. ; *Homœospira baylii* (Dav.) ; and *Nucleospira pisum* (Sow.)? . One new pelecypod *Pterinea konghsaensis* was described by Reed.

The Namhsim series appears to extend into Tonking, according to the recent work of Deprat and Mansuy, where, however, other species also occur, including a number of new ones. (See below).

The Zebingyi beds. These present an interesting and puzzling

problem. They are clearly younger than the Namhsim series and La Touche found that in the Zebingyi section they form a continuous band at the base of the Plateau limestone, and are more intimately connected with the latter than with the Namhsim sandstone, which had either not been deposited in the area occupied by the Zebingyi beds, or had been entirely swept away from that area before the latter were laid down. The whole forms one stratigraphical group of no great thickness and *Tentaculites* occurs throughout. (T. D. La Touche in Reed IV-30. p. 154, footnote). The *Tentaculites* have been identified as *T. elegans* Barr., a form characteristic of the Devonian beds of Bohemia. Associated with these, on the same surface are found graptolites of the genus *Monograptus*, among them being *M. dubius* Suess and *M. riccartonensis* Lapw., the former a Lower Ludlow, the latter a Wenlock species. The trilobite of this formation *Dalmanites swinhoei* Reed is nearly related to a species found in Lower Devonian strata in Bohemia. On the whole this fauna suggests to some extent the late Lower or early Middle Devonian of Bohemia (Hercynian type), but the presence of the Monograpti indicates that the age of the beds is Silurian. There is no positive evidence of a European Upper Silurian or Lower Devonian invasion of this region and despite the Devovian affinities of some of the species, these beds must be regarded as of Silurian, probably Upper Silurian age; a classification which both La Touche and Reed favor, the latter regarding them as transitional to the Devonian.

There is another formation in this region, the Nyaungbaw limestone, consisting of red and chocolate-brown limestone passing into gray blue or purple limestone with *Camarocrinus*, *Scyphocrinus*, and *Orthoceras*. This is placed by La Touche between the Ordovician and Silurian. *Camarocrinus* is represented as usual by what is commonly regarded as the large floating bulb from which the crinoid depended and which made possible the wide distribution of this or-

ganism. The Asiatic species (*C. asiaticus* Reed) is most nearly related to C. *ulrichi* Schuchert from the late Silurian or early Devonian of the

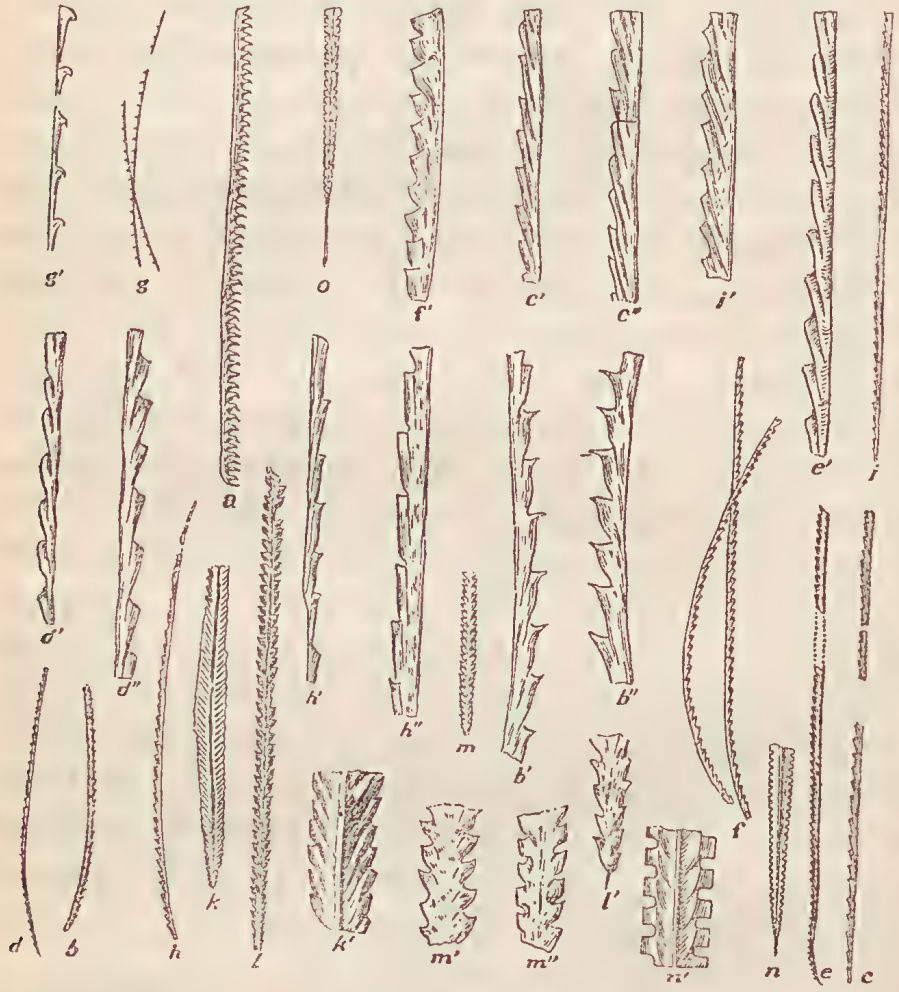


Fig. 78. a-o.—Silurian graptolites of Yunnan. (The figures are copies of European specimens of the species found in Yunnan. Chiefly after Elles and Wood.)

a.—*Monograptus sedgwicki* (Portlock); typical fragment with conspicuous apertural spines.

b.—*Monograptus tenuis* (Portlock); distal fragment; b', distal thecæ in ordinary profile view, (enlarged); b'', another portion (enlarged).

c.—*Monograptus leptotheca* Lapw.; typical median fragment, internal cast in iron pyrites ×1; c', proximal thecæ, part in relief, part as cast (enlarged);

c'', more distal part of same specimen (enlarged).

d.—*Monograptus atavus* Jones; proximal portion ×1; d', proximal portion in relief showing sinuous character of thecæ (enlarged); d'', more distal thecæ, part in relief, part cast (enlarged).

e.—*Monograptus jaculum* Lapw.; proximal portion ×1; e', distal thecæ in relief (enlarged).

f.—*Monograptus concinnus* Lawp.; two specimens, one showing marked ventral curvature ×1; f', distal thecæ (enlarged).

g.—*Monograptus gemmatus* Barr.; two specimens crossing each other ×1; g', distal thecæ, showing form of apertures (enlarged).

h.—*Monograptus incommodus* Tornq.; small distal fragment partly in relief ×1; h', thecæ preserved in relief (enlarged); h'', distal thecæ, compressed (enlarged).

i.—*Monograptus regularis* Tornq.; fragment near proximal end, impression ×1; i', distal thecæ (enlarged).

k.—*Mesograptus magnus* Lapw.; type specimen, part in relief, part as impression ×1; k', distal thecæ, right half relief, left half impression (enlarged).

l.—*Glyptograptus serratus* E. & W.; typical specimen ×1; l', proximal end, reverse aspect (enlarged).

m.—*Glyptograptus incertus* E. & W.; incomplete specimen ×1; m', distal thecæ, reverse aspect (enlarged); m'', distal thecæ, obverse aspect (enlarged).

n.—*Climacograptus rectangularis* McCoy; average perfect specimen ×1; n', portion showing rectangular thecæ ×4.

o.—*Climacograptus tornquisti* E. & W.; large specimen showing tubular virgella ×1.

United States. In America the genus is first known from the uppermost Silurian (Manlius), while in Bohemia it is found in the Lower Silurian (E 1 β and E 2). Unless the position of this Camarocrinus bed is positively determined as at the base of the Silurian, the suggestion might be made that it represents the Upper Silurian (Upper Monroan) of this region.

SILURIAN OF SOUTH CHINA.

Western Yunnan. The presence of Lower Silurian (Niagaran) strata in western Yunnan is shown by the occurrence of shales with *Monograptus* in the Shih-tien region, a few miles south of Yung-Ch'ang-fu in association with the Ordovician strata above described (p. 84). The structure of the region is complicated and these

Silurian graptolite shales appear to be faulted down between beds carrying an Ordovician fauna. The thickness of the beds is over 70 feet, and they are black fissile slates becoming more sandy and lighter colored at the top. Horizons crowded with graptolite remains are found throughout the series, though they become scarce towards the top. No other organisms have been recorded from these beds, which appear to be typical delta or marginal mudflat deposits formed along the western border of the sea by streams bringing muds from the Burma-Tibetan old-land. Two distinct horizons are indicated by the graptolites.

Fig. 79. *Monograptus lobiferus* McCoy; *a*, fragment of stipe in full relief (enlarged). *b*; compressed thecæ, reverse view, still further enlarged, (after Elles & Wood).

The higher horizon yielded numerous species and belongs to the base of the zone of *Monograptus sedgwicki*. The rock consists of a tough fine-grained greenish gray or pinkish flaggy slate weathering yellow, and the most abundant graptolite seems to be *Mono. lobiferus*. The following species have been identified from these beds: *Monograptus sedgwicki* Portl. (Fig. 78a); *M. lobiferus* McCoy (Fig. 79); *M. tenuis* Port. (Fig. 78b); *M. leptotheca* Lapw. (Fig. 78c); *M. atavus* Jones (Fig. 78d); *M. jaculm* Lapw. (Fig. 78e); *M. concinnus* Lapw. (Fig. 78f); *M. gemmatus* Barr. (Fig. 78g); *Glyptograptus serratus* Elles and Wood (Fig. 78 l); *G. incertus* Elles and Wood (Fig. 78m); *Climacograptus scalaris* His. (Fig. 80); *Gladiograptus perlatus* Nich. (Fig. 81); and *Mesograptus magnus* Lapw. (Fig. 78k).

Fig. 80. *Climacograptus scalaris* His. (Enlarged).

The lower horizon consists of tough black carbonaceous and finely micaceous shales or slates, rather coarser in grain and less flaggy than the higher zone. This bed contains abundant *Climacograpti* mostly preserved in scalariform view, and therefore indeterminable, but some seem to be *Climaco. rectangularis;* there is also a suggestion of *Meso. modestus.* Miss Elles considers that this bed probably belongs somewhere in the zone of *Ortho. vesiculosus,* but it may be higher, perhaps at the base of the *Monograptus gregarius* zone. The assemblage is not perfectly convincing, but the abundance of *Diplograptids* and the scarcity of *Monograptus* suggest this correlation.

Fig. 81. *Retiolites (Gladiograptus) perlatus;* portion of the stipe (×2), showing peculiar reticulation of outer surface, (after Nicholson).

The species comprise the following:

Monograptus incommodus Törnq. (Fig. 78h); *M. regularis* Törnq. (Fig. 78i); *M. tenuis* Portl.? (Fig. 78b); *Climacograptus rectangularis* McCoy (Fig. 78n); *C. törnquisti* Elles and Wood (Fig. 78o) and *Mesograptus modestus* Lapw.? (Fig. 82).

These indicate the Lower Llandovery and Tarannon horizons of western Europe and the beds must be regarded as approximately basal Silurian.

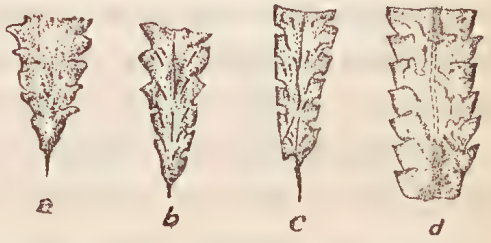


Fig. 82. *Mesograptus modestus* Lap.; *a-c,* lower ends of three specimens in different stages of preservation; *d,* portion of stipe above base (enlarged), (after Elles & Wood).

Eastern Yunnan. In Eastern Yunnan (Kütsing region) the Silurian is more fully represented, the following formations being at present recognized, according to V. K. Ting.

Supper-formation	Middle Devonian
Hiatus and *Disconformity*	
Upper Silurian	Miaokaoshan Group
Middle Silurian absent	Hiatus and disconformity
Lower Silurian	Mientien Group
Hiatus and *Disconformity*	
Sub-formations	Ordovician or older

The Mientien Group. (Lower Silurian or Niagaran). This comprises shales, sandstones and limestones, typically shown in the Kütsing region, especially in the neighborhood of Yihlungse.

The sandstones contain *Lingulella cuneatiformis* Grabau, and *Modiomorpha crypta* Grabau, while in the calcareous beds are found *Spirifer bourgeoisi* Mansuy and *Leperditia* sp.

Middle Silurian appears to be wholly wanting in this region, as indeed throughout much, if not the whole of eastern Asia, the Upper Silurian (Monroan, Upper Gotlandian) resting directly but disconformably upon the Lower Silurian (Niagaran, Lower Gotlandian, Wenlock). This, as we have seen, is the condition found in Europe and in America, though in eastern North America the continental Salina formation intervenes between the marine Niagaran and Monroan.

The Miaokaoshan Group. (Upper Silurian or Monroan). This consists largely of thin-bedded limestones intercalated in shales. It is typically exposed in Miaokaoshan near Kütsing, also between Hsiangsui and Mientien, and again at Sehwaying in Changyi. (Sehwaying limestone). In the limestone of the Miaokaoshan group, in the typical region, the following species

Fig. 83. *Spirifer tingi* Grabau ×2. Yunnan.

have been found: *Spirfier tingi* Grabau (Fig. 83); *Actinopteria mansuyi* Grabau; *Modiomorpha?* sp.; *Hormotoma kütsingense* Grabau; *Holopea yilungense* Grabau; *Orthoceras* sp.

In the Sehwaying beds, the following species have been recognized: *Spirifer tingi* Grabau (Fig. 83); *Polcumita changyiense* Grabau; *Hormotoma* sp.; *Leperditia tingi* Grabau.

The higher beds of this series are characterized by *Leperditia* and fish remains. This same horizon appears also to underlie the Middle Devonian beds with *Athyrisina plicata* (Mansuy) in the Nanning region of southern Kwangsi, to judge by the occurrence there of *Spirifer tingi*.

This horizon has many characters in common with the Monroan of North America, and appears to represent an invasion, from the south, of a Pacific fauna.

From To-Kuan-ting (Huang-Kuo-tsao, and Hui-lung-chi) in northeastern Yunnan, specimens of cephalopods (*Trochoceras* and *Orthoceras*) have been obtained, which are regarded as representing an early Silurian horizon (Yabe and Hayasaka, IV, 39).

Further west in eastern Yunnan at Si-Yang-tang, beds with *Spirifer bourgeoisi* and other species have been found, representing apparently the Niagaran horizon. Originally these were referred by Deprat to the Ordovician, but this error was corrected by Mansuy.

These beds seem to mark a shore-facies of the Silurian sea, this being suggested by the crustaceans *Ceratiocaris* and *Sinocaris* found in these beds. The list of species obtained is as follows: *Spirifer bourgeoisi* Mansuy, *Orbiculoidea sinensis* Mansuy, *Leda circumflexa* Mansuy, *Goniophora contraria* Mansuy, *Sinocaris asiatica* Mansuy, *S. barbagii* Mansuy, and *Ceratiocaris pierloti* Mansuy.

Tonking.—Silurian strata are well developed in central and north-eastern Tonking. In some of the horizons, species suggestive of Ordovician affinities seem to linger and these are probably to be con-

sidered as indicating a very early Silurian age. In other sections the fauna is the typical European Silurian fauna, with however, always an admixture of species not known so far from other localities. A certain number of species is found in common between this region and the Burmese and Indian localities, but this number is not very large. A few corals occur, including *Heliolites megastoma* (=*H. decipiens*), *H. grayi* and *Favosites gotlandica* and others less definitely identified. *Halysites* has not been reported, but *Syringopora* is represented by a new species (*S. tonkinensis*). *Climacograptus* cf. *scalaris* His. represents the graptolites. The brachiopods, like the identified corals, are chiefly European Silurian types, including such forms as *Dalmanella testudinaria*, *Spirifer crispus*, *S. sulcatus*, and *Schuchertella pecten*. *Chonetes* is a common genus, being represented by 6 species, only one of them (*C. striatella* Dalman), being known from Europe, while the others are new. The pelecypods are all new species but the gastropods suggest the American Guelph horizon. The only positively identified trilobite (*Proetus namanensis* Mans.) is new and so are the ostracods.

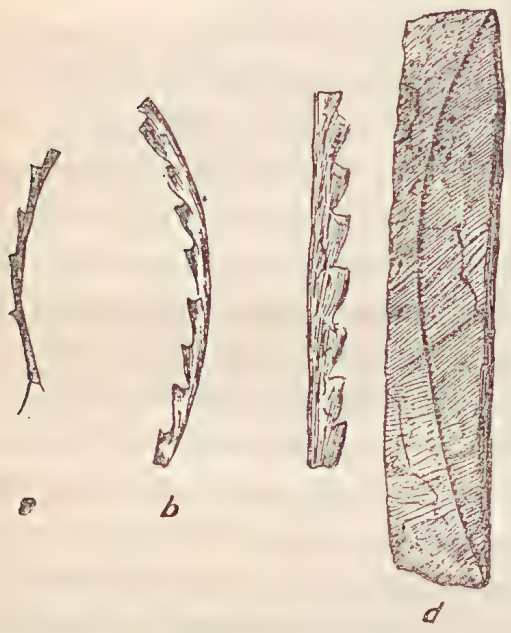


Fig. 84.

Linograptus nilssoni Barr.; *a*, lower part of stipe with sicula; *b*, thecæ of proximal part enlarged; *c*, another portion enlarged; *d*, part of a branch or stipe on shale, nat. size (*a-c*, after Elles & Wood, *d*, after Barrande).

It is at present impossible to say whether or not more than one horizon is represented. The Lower Silurian (Niagaran) is

certainly present, and though it has a certain individuality, it is essentially a derivative from the European Silurian fauna. Whether any of the horizons represent Upper Silurian (Monroan), can not at present be determined, but it is probable that certain strata from the Van-yen region which have furnished *Leiorhynchus* sp. *Leperditia tonkinensis*, *L.* cf. *angelini* and *Ceratiocaris* cf. *robustus* Salter, represent the Upper Silurian.

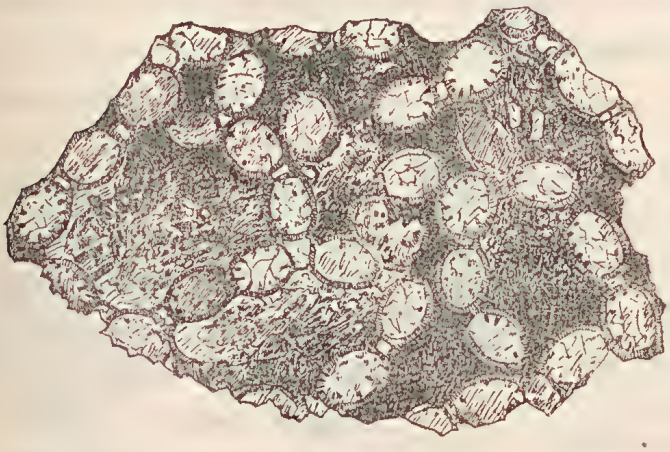


Fig. 85.
Halysites pycnoblastoides Yabe. Portion of a polished surface enlarged ×5. Hupeh. (After Yabe).

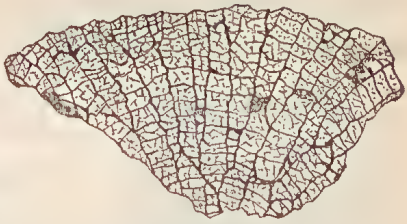


Fig. 86.
Favosites gotlandicus Lam. Vertical section ×2. Hupeh. (After Yabe).

SILURIAN OF CENTRAL CHINA.

NANKING HILLS. In the southern slope of the Lun-shan, near Nanking, and Chinkiang, in the province of Kiangsi, the early Upper Ordovician Lunshan limestone is disconformably succeeded by graptolite-bearing shales, which represent the lowest Silurian (Niagaran) horizon. The following species have been obtained from these shales according to Frech:

Fig. 87.
Dalmanella aequivalvis (Dav.) with enlargement of surface.

Climacograptus scalaris L. (Fig. 80); *Linograptus nilssoni* Barr. (Fig. 84); *Diplograptus* sp.; *Retiolites?* sp.

The age of the beds is Lower Llandovery, and they correspond essentially to those of west Yunnan.

Fig. 88.
Pentamerus borealis Eichw. Hupeh. (After Frech.)

HUPEH. From Loling-po, near No-lu-ping, Tung-hu-hsien, in the south part of the province of Hupeh, Yabe and Hayasaka report grayish marly limestone with the following typical Lower Silurian fossils:* *Halysites pycnoblastoides* Ehrenberg (Fig. 85); *Favosites gotlandicus* Lam. (Fig. 86); *Dalmanella æquivalvis* Davidson (Fig. 87); *Pentamerus borealis* Eichw. (Fig. 88). The last species, *Pent. borealis*, is also reported by Frech from Ichang in Hupeh province.

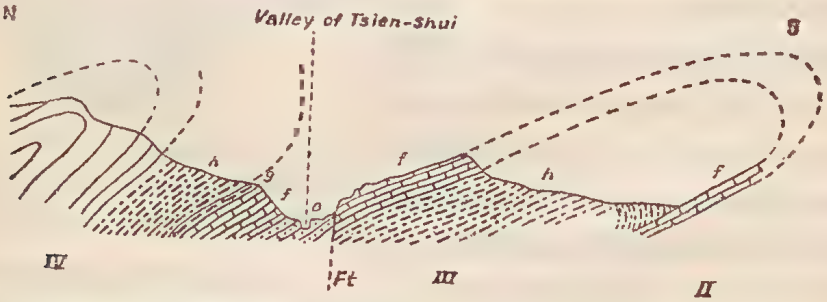
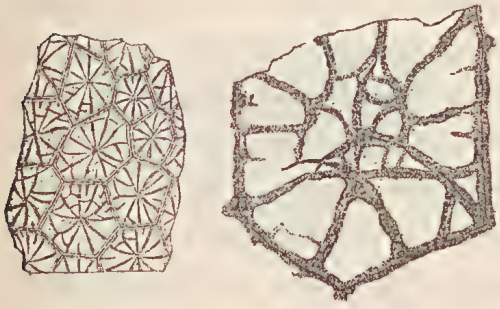


Fig. 89. Section of the Silurian strata of the overturned anticlines of Ning-Kiang-chou (III), and Tchau-pi-shan (IV), with the Tsien-shui fault between. *e*, white and yellow quartz sandstones (Carb.); *f*, Carboniferous limestone (600 ft.); *g*, Devonian limestones *h*, Silurian shales and limestones with fossils. (After v. Richthofen).

TSINGLING REGION. The classical region for the Silurian of China is found in the southern foothills of the Tsingling-shan, in

*For description see Yabe and Hayasaka, IV-39 p. 83 et seq.

northern Szechuan and the adjoining region of southwestern Shensi and southern Kansu. Here strata of this system were originally discovered by von Richthofen, and the fossils were described by Lindström and Kayser. The strata comprise the following succession in descending order: (Fig. 89).



a *b*

Fig. 90.
Ceriaster calamites Lindstr.; *a*, transverse section of corallum; *b*, a single corallite enlarged; showing a three-partite character from budding. Szechuan. (After Lindström).

SUPER - FORMATION—CHAUPISHAN FORMATION Upper Devonian.

Hiatus and Disconformity.

CHAOTIEN FORMATION—Green shale with intercalation of coralline limestone nodules, with many brachiopods and corals (bed h. of v. Richthofen).

CHIENSHUI LIMESTONE — Impure argillaceous limestone beds with many corals. (Bed i. of v. Richthofen).

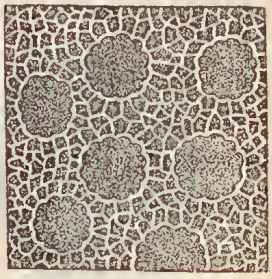


Fig. 91.
Heliolites interstinctus. Linn. Enlarged cross-section. Szechuan. (After Lindström).

HUANGPAYI FORMATION—Dense red limestones, with numerous crinoidal fragments and brachiopods, alternating with shaly layers, (Upper part of bed l, and perhaps bed k, of v. Richthofen).

Probable hiatus and Disconformity.

SUB-FORMATION—Kiautchangpa limestone (Ordovician), bed l in part, of v. Richthofen).

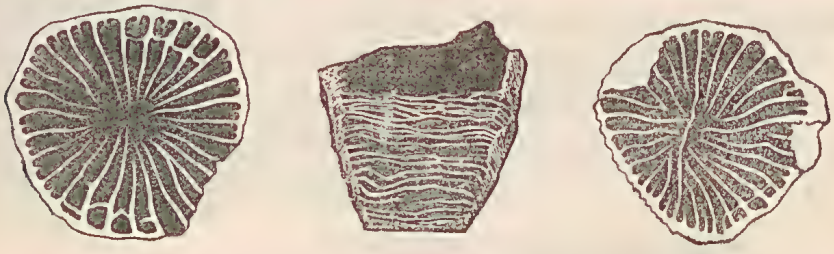
The HUANGPAYI FORMATION contains brachiopods: *Spirifer elevatus* Dalm. *S. interlineatus* Sow. and *Rhynchonella borealis* var. *sinensis* Kayser, (6) and the corals *Ceriaster calamites* Lindström, (Fig. 90) and *Synamplexus viduus* (Lindström) (8).

The CHIENSHUI LIMESTONE abounds in corals, some of which extend into the next higher formation. These include the genera *Alveolites*, *Heliolites* (Fig. 91), *Plasmopora* (Fig. 92), *Halysites* (*H. catenularia* L.), *Amplexus* (Fig. 93), *Cyathophyllum*, *Ptychophyllum* (Fig. 94), *Platyphyllum*, and *Cystiphyllum* (Lindström 8).

Fig. 92. *Plasmopora tubulata* Lonsd. Cross-section.

The CHAOTIEN LIMESTONE contains the following brachiopods, besides gastropods, orthocera, trilobites and crinoid remains (Kayser 6): *Atrypa reticularis* Lin.; *Merista tumida* Dalm.; *Strophomena shönnsüenensis* Kayser; *Spirifer elevatus* Dalm.; *Spirifer interlineatus* Sow.; *Orthis bouchardii* Dalm.; *Nucleospira pisiformis* Hall; *Atrypa? tshantienensis* Kayser; *Rhynchonella* sp.

As is seen from their fossils, these beds are intimately related to those of northern and western Europe. They show no species in common with the Silurian beds of eastern Yunnan, but they correspond essentially to the Konghsa marls of Burma. Hence we are justified in considering



b *a* *c*

Fig. 93. *Amplexus appendiculatus* Lindst. *a*, longitudinal section; *b*, transverse sections; *c*, a somewhat lower transverse section. Szechuan. (After Lindström).

that they entered the Chinese basin by the southern passage (Himalayan geosyncline).

SUMMARY OF THE SILURIAN OF CHINA.

So far as our present very limited knowledge of the Silurian

rocks of China permits us to judge, both Lower and Upper Silurian (Niagaran and Monroan) are present, and these are separated by a hiatus which represents the Middle Silurian. Thus the development corresponds to the known development of this system in America and in Europe, in both of which the Middle Silurian is unrepresented by marine strata.

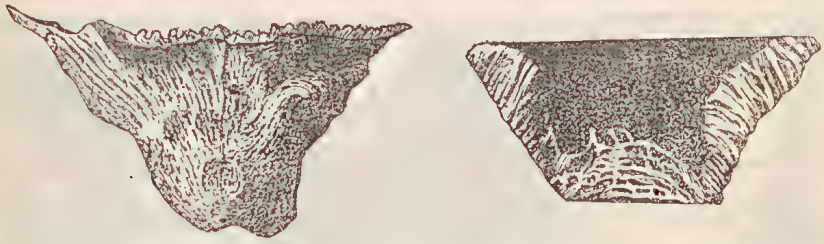


Fig. 94. *Ptychophyllum cyathiformis* Lindström; side view, and section. Somewhat reduced. Szechuan. (After Lindström).

Very early in Silurian time, indeed at the very opening of the period, the sea entered the Chinese basin by way of the Himalayan geosyncline. Unfortunately we know too little of the deposits of central and western Asia to permit us to speak with certainty of the location of the water-way between northern India and eastern Europe, but that such a water-way existed is beyond doubt from the similarity of the bulk of the Chinese Silurian fauna to that of Europe. The probabilities are that it extented through Russian Turkestan, to the north of the Aral and Caspian Seas, to the Timan, where these strata are known. (See Maps, Figs. 77 and 95).

In its long journey across Asia the fauna became modified to a certain extent, though many of the corals and brachiopods retain essentially their specific character. The graptolites, being planktonic and quickly distributed, remained specifically unchanged. Further study of the Silurian of China will probably reveal the presence of a much larger number of forms peculiar to this region, species which have arisen within the nearly circumscribed basin which China presented. This indeed is indicated by the large number of new

forms which has already been described from Tonking, that being an area which lay within the southern part of this Chinese basin.

How complete the development of the Lower Silurian (Niagaran) of China is, can not at present be ascertained, nor is it known what the total thickness of the formations amounts to. All that we can say is, that this division is well represented by strata probably

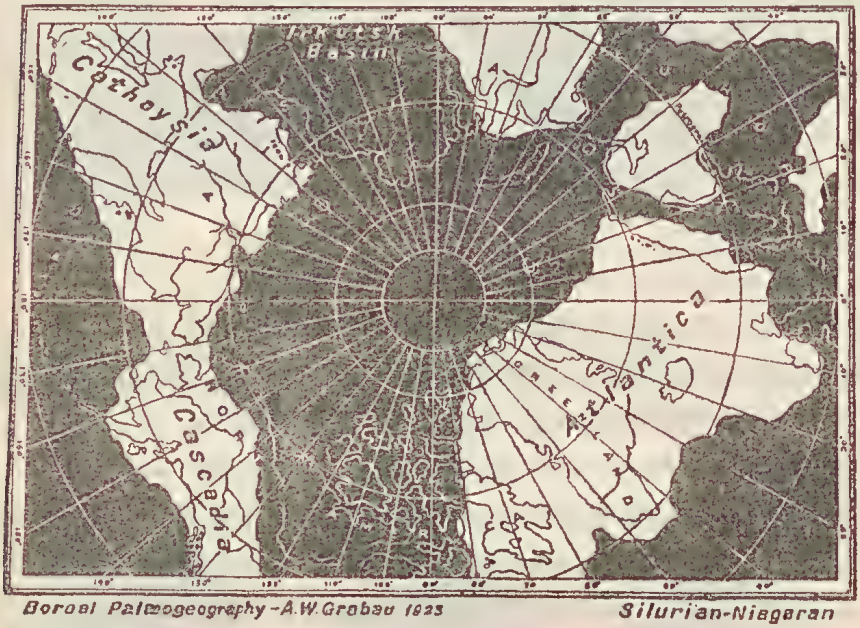


Fig. 95. Palæogeographic map of the Arctic region showing the distribution of land and water (black) in Lower Silurian (Niagaran) time, and the routes of migration of faunas between Eur-Asia and North America.

several hundred feet thick, but that it is restricted to central and southern China. Northern China appears not to have been covered by the sea in Silurian time; no strata of this age now occur, and it is extremely unlikely that they did occur in north China, and were again removed by erosion before late Dinantian time.

The Upper Silurian (Monroan) beds appear to have been mostly restricted to a small area in eastern Yunnan, south-western Kwangsi, and perhaps Tonking. The faunas of these beds are strikingly distinct from those of the Lower Silurian, consisting entirely

of small *Spirifers* and of depauperate-appearing pelecypods, together with numerous ostracods, mostly however of the genus *Leperditia*. There is in these beds a total absence of the normal Silurian elements of Europe. The fauna bears a remarkable resemblance to that of the Manlius limestone of New York and to that of the Lower Monroan of Michigan, etc. in the U. S. A. This suggests that it was derived from a region which presented similar physical conditions to those which characterized the region from which the lower Monroe and Manlius faunas of North America were derived, i.e. the east central Pacific. The most likely region which could have furnished these Upper Silurian faunas of China, is the Indian Ocean, which, being on the opposite side of the earth from that furnishing the corresponding American phase of this fauna, may have borne a close physical likeness to it. I have therefore considered this Upper Silurian sea as an invasion from the Indian Ocean. Connection with European waters appears not to have existed at that time, or at any rate not to have been very marked.

Whether this connection with the Indian Ocean also existed in Lower Silurian (Niagaran) time, is a point not readily determined. True, there are several small *Spirifers* such as *S. bourgeoisi* and other forms in that fauna, which might have been derived from Indian Ocean sources. Still it must be remembered that forms of this type had become established in the Atlantic fauna and possibly in the Boreal fauna as well. It is not so much the presence of these small forms in the Upper Silurian fauna of China that suggests invasion from the Indian Ocean, as it is the absence of the normal marine fauna of the northern and western regions, which points to a disconnection of the Chinese basin from the European waters. Hence the Indian region could alone furnish the fauna at this period.

This final temporary invasion of China by the late Silurian sea, was apparently of short duration only. It was followed by a

complete withdrawal of marine waters from China. During the succeeding Lower Devonian period, this region, as indeed the greater part of Asia, was dry land. This will be more fully set forth in the next chapter.

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CHAPTER VI.

THE DEVONIAN SYSTEM.

History and Subdivisions.

Historically, the Devonian system is the longest known system of China, for the first Chinese fossils to be described were of Devonian age, having been brought to Europe by travellers who purchased them in medicine shops (7, and 31). But though the fossils have been known for close on to a century, very little detail of the stratigraphy of this series in China is known. Von Richthofen scarcely met with satisfactory exposures,-though he held that Devonian rocks were widespread, and Willis and Blackwelder did not see these formations at all. Von Loczy (40, 41) is perhaps the only one of the earlier explorers who actually investigated undoubted Devonian formations in the field. More recently Deprat (III, 7) gave an elaborate account with sections of the Devonian of Yunnan, but since much doubt has been thrown on the accuracy of Deprat's work, we can not accept his results as final. Indeed, the subsequent detailed work carried out by V. K. Ting in eastern Yunnan seems to negative some of Deprat's results. Unfortunately, Dr. Ting's results have not yet been published, but the fossils he collected have been studied by me, and the brachiopods have been described in a memoir that will appear shortly (19). The only recent work done in the Devonian formation of the Tsingling-shan is that by Prof. L. Wang of the National University, Peking, who travelled in that region in 1922. His stratigraphic results are however not yet available. In order, however, that we may understand the real significance of the Chinese Devonian formations and the light which they throw on the Devonian history

of the earth, it will be necessary for us to briefly review the general character of the Devonian formations in other countries, and attempt to determine the relationship which they hold to the Chinese Devonian formations.

Two standards for comparison are generally recognized in Devonian stratigraphy, namely the American and the European. The former is based primarily upon the development in the State of New York, the latter upon the German and Belgian development. The two standards are here given, since both are necessary for the understanding of the Devonian problems in China.

Table of Devonian Subdivisions:

American Standard.	European Standard.
UPPER DEVONIAN.	UPPER DEVONIAN.
Chautauquan division.	*Famennian division.*
Catskill and Chemung.	
Senecan division.	*Frasnian division.*
Portage group.	
(Naples, Ithaca, and Oneonta phases).	
Genesee-Tully group.	
MIDDLE DEVONIAN.	MIDDLE DEVONIAN.
Erian division.	*Givétian division.*
Hamilton group.	
Ulsterian division.	*Eifelian division.*
Marcellus-Onondaga.	
Schoharie-Esopus.	

Lower Devonian.	Lower Devonian.
Oriskanian division.	*Coblentzian division.*
Oriskany-Port Ewan beds.	
(Hiatus).	
Helderbergian division.	*Gedinnian division.*
Alsen limestone.	
Becraft limestone.	
New Scotland shales.	
Coeymans limestone.	

Characteristics and Distribution of the Devonian Formations.

LOWER DEVONIAN.

The Silurian and Devonian form a continuous marine series in eastern North America, in the basin of the Appalachian geosyncline. Over a large region the uppermost Silurian strata are represented by the Manlius limestone which carries the depauperate south Pacific fauna before noted. Underlying it in many sections, is a limestone with the Boreal coral fauna, and the absolute distinctness of the two faunas can scarcely be explained except on the basis of invasion of the region by waters of decidedly different temperatures, warm waters from the Boreal realm, cold from the Pacific. But the warm water fauna (upper Monroan), which in late Upper Silurian time covered most of North America, succeeded in occupying part of the Appalachian trough, and remains of it are found today in the fossils of the Kayser formation of Maryland and Virginia. The fauna of this formation is essentially the same as that of the so-called Helderbergian formation in Arctic America (Series B, Southwestern Ellesmereland, Holtedahl—IV, 19) and the fauna of that formation, if Devonian, must be regarded as derived from the Upper Silurian fauna,

which may have continued on into Lower Devonian time within the Boreal region, with only moderate changes.

In the Appalachian trough, however, into which this late Silurian fauna had wandered (across Michigan and Ohio) in upper Monroan time, and where for a while it existed side by side with the Manlius fauna from the south, this fauna (with *Gypidula præcursor*) continued into Lower Devonian time. The opening of this period was marked in North America by the withdrawal of the waters of the interior towards the north, so that the greater part of North America became dry land, and by the closing of the southern outlet of the Appalachian geosyncline to the Pacific, probably by the development of a low land arch, which later rose to form a mountainous barrier on the South. Thus, the (supposedly) cold water faunas of the Pacific were excluded from the Appalachian trough, where only the relict Boreal fauna lingered. It was this fauna, which, in the isolated water body thus created,* developed into the lower Devonian fauna of eastern North America. As this long narrow trough was open to the Atlantic on the north-east (region of the present Gaspé peninsula of eastern Canada), certain elements of the Atlantic fauna of the period could wander in, and become incorported in the fauna, but at first this seems not to have been the case to any marked extent. Thus the Helderberg fauna of eastern North America became a unit, distinct from other faunas of the same period, but having its nearest affinities with the contemporaneous early Devonian faunas of the Boreal sea which also, but independently, developed from the late Silurian fauna, a remnant of which had become the ancestor of the Helderberg fauna of North America.** After the deposition of several hundred feet of

*For map of this water body see Grabau, Textbook of Geology Vol. II p. 403 Fig. 1287.

**The author is here presenting his own views of the origin of these faunas, based on many years of study. These views are not shared by all geologists at present.

limestones and shales in the Helderberg trough, the sea slowly withdrew to the north-east, draining the trough and leaving the previously deposited strata exposed to erosion. In the north-eastern end of the trough, however, the sea continued to linger, for on the Gaspé peninsula of eastern Canada, we find that these Lower Devonian limestones (Saint Alban and Cape Bon Ami limestones) have a thickness of about 1,200 feet, only the basal part of which corresponds to the Helderbergian of New York, the remainder being formed during the period of sea retreat from the Appalachian trough. The Gaspé limestone is followed by some 800 feet of limestones (Grand Grève limestone) which were deposited during the re-advance of the sea in late Lower Devonian time. In the Appalachian trough the products of erosion of the older strata were accumulating in certain regions, while wind-blown quartz sands were carried from Appalachia and other regions, across a wide land area. With the re-entrance of the sae into the trough, the erosion products were reworked to form the Port-Ewan beds, and the sands to form the Oriskany sandstone. With the continuous spread of the sea, the waters from the north again came in contact with those in the Appalachian trough, and a new element, the Boreal, was added to the Oriskany faunal element, which had entered from the Atlantic. Out of these combined elements arose the Schoharie fauna, during a period when the mud delta of the Esopus shale formed a more or less effective barrier to the further invasion of the trough of Atlantic elements. Finally the sea-connections had become so complete that the warm waters of the Boreal province with their coral faunas, (derived by evolution within the province from the Silurian coral faunas) could spread far and wide over North America, and become instrumental in the formation of the Onondaga limestone.

One fact must, however, clearly be kept in mind, for it has an important bearing on the Devonian history of Asia. The Lower

Devonian sea was no longer as extensive in the Boreal region as it had been in Silurian time. With the end of that period, when western Europe suffered the disturbances which created the Caledonian moun-

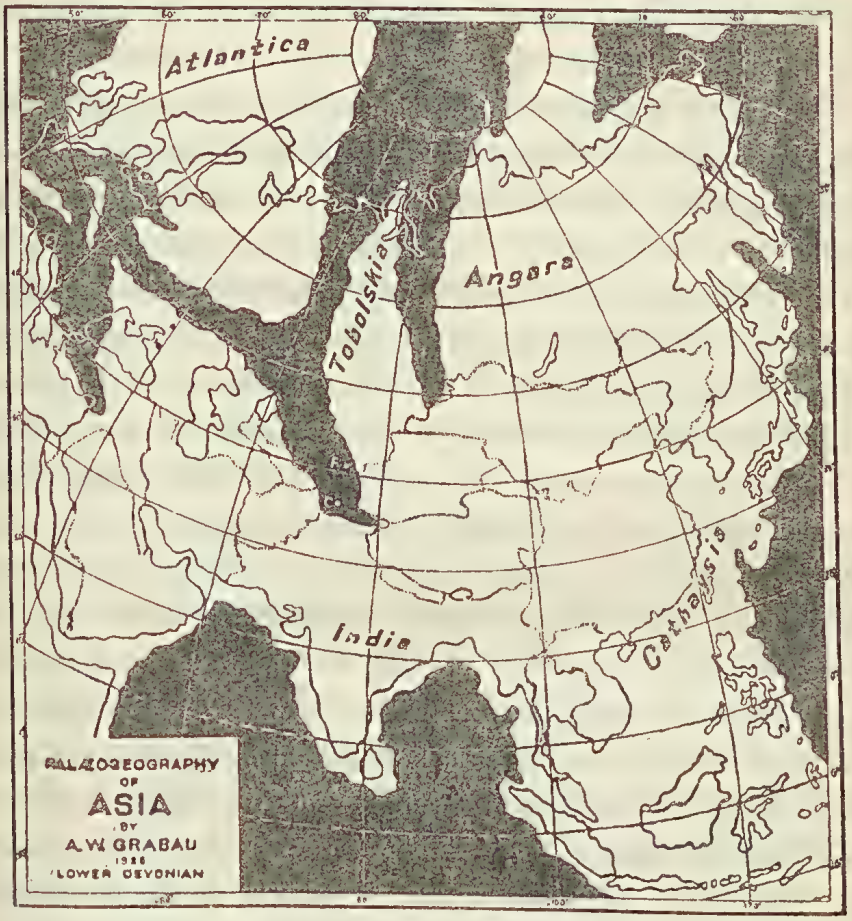


Fig. 97. Palæogeographic map of Asia showing the probable distribution of land and sea (black) in Lower Devonian time. C=Chowar Shur, F=Ferghana.

tains, the American continent also became dry, except for the Appalachian trough, while the land barrier between this and the Pacific arose on the south. Northern Asia too, suffered disturbances, for the strata of the old Yenissei-Irkutsk-Lena geosyncline became folded into a series of semicircular mountain chains, while a new belt of geosynclines came into existence outside of these mountain chains. This new

geosyncline thus lay in the old-land outside of the location of the Silurian geosyncline, and the Silurian and Devonian strata were deposited in separate belts. The whole interior of the Irkutsk or north Siberian basin, also became dry land, and remained so until long after the end of Palæozoic time.

It was this newly formed land-mass "Angara-land", which apparently continued northward, extending across the polar region to join the land-mass of Mackenzia which then divided northern North America into two parts.* It was only in the western part of this region, in Eur-Asia, that a water body (Fig. 97) which lay next to (east of) the old-land of Atlantica, entered the main land of to-day. One arm extended southward in the Ural geosyncline while a second reached southward across Siberia to the Salair mountains of today, one of the limited number of localities in Asia in which Lower Devonian fossils have been found. It is quite possible that the Lower Devonian of the Urals, which is repeated in the Salairs, represents as nearly as may be, the Lower Devonian fauna of the Boreal region in its greatest purity. Certain it is, that no other locality known was in such direct connection with the Boreal region. It is not likely that direct connection existed between these geosynclines and the southern part of the Baltic geosyncline for along the Russo-Baltic border the Lower Devonian strata are either absent or represented by continental beds. That such connection existed in spite of this, is indicated by the repeated occurence in the Siberian region, of one or two species typical of the late Lower Devonian (Coblentzian) of Germany. Connection with the central European region is further shown by the

*The maps of the Devonian seas of North America published by the author in his Textbook of Geology Pt. II need correction in the light of the knowledge gained from the study of Asia. On these maps (pp. 403-411) Mackenzia is represented as ending in a point on the north whereas it should remain approximately of the maximum width to the northern edge of the map, continuing on the other side in the Angara-land extension.

numerous marked Bohemian elements in the Lower Devonian of the Urals. This line of connection has been carried on the map across southern Russia, approximately along the fiftieth parallel. One of the characteristics of the Lower Devonian fauna of the Urals, as described by Tschernyschew (68, 70), is the evident suggestion of Silurian affinities in the fauna. This is not at all surprising when we realize that this fauna is directly derived from an Upper Silurian fauna in a neighboring region. That the essential elements of the Helderberg fauna were also derived by modification within a circumscribed area, of a disassociated remnant of the northern late Silurian fauna, would further tend to the production of certain similarities of the two faunas, without, however, effecting specific identity. Such similarity would be the result of parallelism in development under corresponding similar physical conditions.

LOWER DEVONIAN OF CENTRAL ASIA.

The border region of Turkestan, Afghanistan and northern India is at present the only region in central Asia from which Lower Devonian faunas have been recorded. The localities which have furnished these are: eastern Ferghana (long. 72° 10' to 74° 20' N., lat. 40° to 41° 20' E.) (Muschketow 51), and elsewhere in Turkestan (v. Weber 74), and Showar Shur in the Hindukush of Afghanistan (long. 73°35' N., lat. 36° 50' E.) (Reed 61). The fauna described by v. Weber, and that listed by Muschketow are both characterized by a remarkable preponderance of the Bohemian or Hercynian element, an element equally characteristic of the Lower Devonian fauna of the Urals. As in the latter case, a certain Silurian element seems to be in evidence, as signalized by such species as *Dalmanella elegantula* (Dalm.), *Plectambonites transversalis* Wahl., etc. Characteristic forms common to the eastern Ural, (Bogoslofsk limestone) and the Ferghana region, include *Atrypa reticularis* Linn.,

A. granulifera Barr., *A. marginalis* Dalm., *Rhynchonella princeps* Barr., *R. nympha* Barr., *Sieberella sieberi* v. Buch, *Spirifer uraloaltaticus* Grünew., *Karpinskya coniugula* Tschern., *Strophomena stephani* Barr., and others, besides *Spirifer paradoxus* Schl., and *Cyrtina hetoroclyta* Defr., characteristic species of the upper Coblenzian of the Rhine district. The fauna occurs in a white and light gray granular limestone which forms the lower part of a calcareous and siliceous series, at least 1000 meters in thickness, and which also includes the later Middle Devonian with *Stringocephalus burtini*, the Upper Devonian, Dinantian and Upper Carboniferous. The fauna obtained from Showar Shur also includes *Sieberella sieberi* von Buch, a *Spirifer* related to *S. primævus* Stein. of the Taunus quartzite and Siegen graywacke of the Rhenish Lower Devonian, *S.* cf. *robustus* Barr., *Stropheodonta phillipsi* Barr., *Orthothetes hipponyx* Schnur, etc.

There seems little possibility of connecting these central Asiatic Lower Devonian deposits directly with the Bohemian region, since the evidence at present available negatives the extension of the Mediterranean Sea across the Persian region. Moreover, the very close relationship which exists between these central Asiatic faunas and those of corresponding age in the Urals, leads us to regard the connection as most direct with the latter district. The characteristic Rhenish species found in these deposits point to a similar connection. Hence, upon the map I have extended the Uralian embayment to this central Asiatic region, but it must be distinctly understood that this represents merely an interpretation of the available facts, and is by no means established. There is at present no evidence to show that this embayment of the Lower Devonian sea extended into the Himalayan geosyncline, for the Burmese deposits, with forms suggestive of the Hercynian, are shown to be Silurian by the occurrence of typical Silurian graptolites (See *ante*, p. 121). Furthermore, there is at present no conclusive evidence, that the Lower Devonian sea extended

into the Chinese basin. It is true that Mansuy has described a fauna from eastern Yunnan which he considered to represent the Lower Devonian. This determination was based on the identification of an imperfectly preserved shell impression, as a variety of *Sieberella sieberi*. As will be more fully shown later, this identification is extremely doubtful, and the other fossils associated with this shell, have Middle, rather than Lower Devonian affinities. We are thus forced to conclude, that the Lower Devonian sea did not extend into China, and that deposits of this age, where formed, were of purely continental character.

LOWER DEVONIAN OF THE ALTAI REGION.

In addition to the Lower Devonian of the Kusnezk basin and the Salair mountains, strata of this age have also been described from the southwestern part of the Altai mountains to the south of the Kusnezk basin (Tschernyschew 71). The fauna was obtained from the limestones in the Krjoukowski mine and is of Coblentzian affinities. The fauna contains a number of trilobites, including *Harpes reticulatus* Corda, *Proetus ahlerti* Bayle and several new species (*Phacops altaicus*, *Bronteus sibiricus*, *Proetus sibiricus*); the cephalopods *Goniatites* (*Anarcestes*) *lateseptatus* Beyr., and *Orthoceras albense* Tschern; the gastropod *Platiceras disjunctum* Giebel var. *altaica;* and the brachiopods *Meristella upsilon* Barr. (?), *M? altaica* Tschern., *Whitfieldella tumida* Dalm., *Spirifer sibericus* Tschern., *S. altaicus* Tschern., *Strophomena solaris* Barr.? and *Chonetes embryo* Barr. The prevailing types are western European, many of them allied to the species of the Bohemian stage F2 (Konjepruss), as is also the case with the species of the Urals. The coral element suggestive of American affinities is absent, and these beds probably represent a different horizon in which European forms predominate. The area in which these deposits were found was probably an extension of the

Salair embayment, and not directly connected with the central Asiatic region.

LOWER DEVONIAN OF THE ATLANTIC PROVINCE.

The lower Devonian fauna of the Atlantic province is probably developed in its greatest purity in the great series of formations which represent this division in the Rhine district of western Germany. It is true that this series of formations consists largely of sandstones and shales, and in a measure represents the material brought by the rivers from the old-land of Atlantica on the north-west, and deposited near the shore, and, for the most part, in shallow water. As a result only one phase of the Devonian life, that of the shallow water, is represented. A more calcareous phase however is found in the Harz Mountains, and in the Thuringian region in Germany, where lentils of limestone enclose the so-called Hercynian fauna, a rich assemblage of trilobites, brachiopods and gastropods. A more special phase of this fauna is found in the basin of Bohemia, where, in the vicinity of Prague and Beraun, is found the Konjepruss limestone, which encloses a wealth of organic remains. This is the division named by Barrande F-2. It is underlain by a dark limestone (F-1, of Barrande), which represents the uppermost member of the Silurian, being separated from the underlying Lower Silurian (F-2, Niagaran) by a pronounced hiatus and disconformity, but apparently continuing without interruption of sedimentation into the overlying Konjepruss limestone. The fauna of the Konjepruss limestone is a complex of several facies, most marked among which is the reef facies. This is characterized by a great development of corals and brachiopods, and by peculiar, mostly thick-shelled gastropods. Trilobites are rare, and goniatites are absent, while nautiloids are only found occasionally. Among the brachiopods the pentameroid shell is especially characteristic, while the gastropods present a large

series of forms which have lost the ability to coil, at least in their adult stages. Such loss of power for spiral growth indicates racial senility or phylogerontism in the types thus affected. It is generally possible to refer such senile types back to Silurian ancestors of normal form. These non-coiling gastropods are generally referred to the genus *Platyceras*, though these forms are not congeneric, but represent end-members of many different genetic lines. It is an interesting fact, that the only other horizons in which gastropods of this type are found in abundance is in the Helderberg and Oriskany beds of the Appalachian trough, and it is quite possible that these so-called American *Platyceras* represent a case of parallelism in degeneration with those of Bohemia, both occurring under the conditions of isolation enforced in similarly circumscribed basins.

Trilobites are common in another facies of the Konjepruss limestone, and they are generally forms with large spinous pygidia, belonging to the generic groups *Bronteus*, *Proëtus* and *Cyphaspis*. Some of these are represented by numerous species.

In general, this fauna has a wide distribution in southern Europe, occurring on the one hand in southern France and northeastern Spain (Barcelona region), and on the other in the Carnic Alps and as far east as the Bosphorus. Beyond that, however, no indications of this fauna have been found, for in the neighboring parts of southwestern Asia, the Devonian, where present, begins with strata of Middle Devonian age.

MIDDLE DEVONIAN.

Ulsterian or Eifelian Epoch. Throughout the known parts of the world the seas of the Middle Devonian period arose by insensible steps out of the Lower Devonian seas. No world-wide negative eustatic or retreatal movement, such as heralded the opening of Middle Silurian time affected the waters of the earth in the Devo-

nian period, though movements of this type occurred in the Appalachian geosyncline during Lower Devonian time as we have seen. The renewed transgression of the sea, which in North America culminated in the production of the Oriskany sandstone, continued without interruption into Middle Devonian time. But the fact of significance in the opening stages of the Middle Devonian was that the transgression became world-wide, affecting the various marine basins, which again tended to become confluent. Thus the Boreal waters mingled with the Atlantic waters in the seas of the interior of North America. For a time the ingress of the Atlantic waters into the Appalachian trough was made more difficult, if it was not wholly prevented, by the building of great mud-deltas by rivers from the old lands which bordered it. The remains of one such delta built by a river from Appalachia, are preserved in the Esopus shales of eastern North America. It was this partial interruption that gave the Boreal fauna its advantage and thus we find that the first manifestation of this fauna in the Schoharie formation was wide-spread in North America. It was followed by the Onondaga fauna which again introduced the coral element of the Boreal seas into the North American waters. As was long ago pointed out by Stuart Weller, this Onondaga fauna is a direct derivative of the older Silurian fauna, the modification having taken place within the Boreal realm. I have myself shown the marked resemblances in the coral and hydrozoan elements between the upper Monroan (late Upper Silurian) and the Onondaga. Such similarity also exists among some of the brachiopods, while the gastropods and cephalopods still retain their Silurian affinities. J. M. Clarke has shown, that the cephalopod element of the Onondaga is of Atlantic origin, and this is also true of some brachiopods, notably *Spirifer acuminatus*, which is equally at home in America and in western Europe.*

*For further details see A. W. Grabau, Text Book of Geology, volume 2 pp. 402 et. seq.

The Schoharie-Onondaga transgression belongs to the first half of the Middle Devonian period, that one which is generally referred to as the Ulsterian in America, and the Eifelian in the European nomenclature.

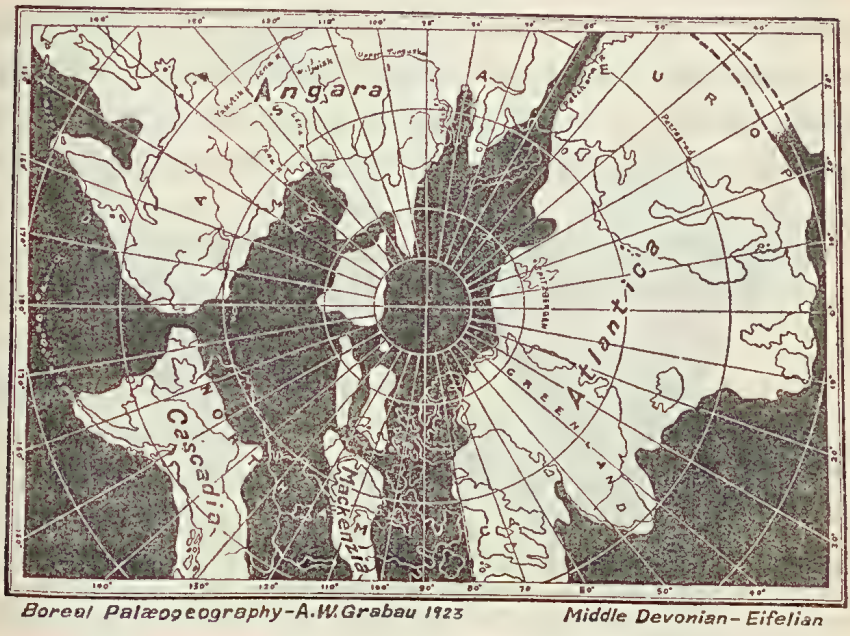
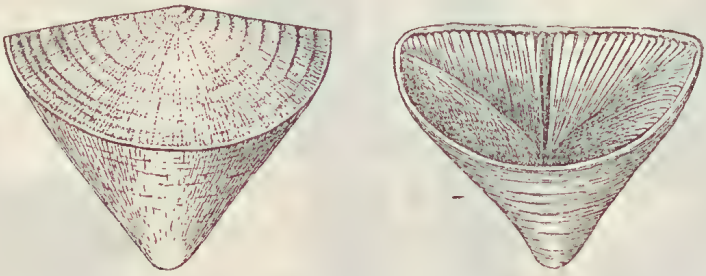


Fig. 98. Palæogeographic map of the present north polar region showing the marine waters (black) which probably extended across it in early Middle Devonian (Eifelian-Ulsterian) time, permitting migration of faunas between America and Eur-Asia. The Altai embayment (80th meridian E.) was probably joined to the Tomsk channel as shown in Fig. 101.

This transgression was not marked in the Eur-Asian extensions of the Boreal sea, indeed there seems to have been a partial or temporary withdrawal of the waters probably followed by a re-advance, comparable to, though probably not contemporaneous with, the Oriskany withdrawal in the Appalachian trough. This is suggested by the absence of rocks of early Eifelian age in the eastern Urals and in the Altai mountain region and by the presence above the Lower Devonian limestones, of unfossiliferous, probably continental, sandstones on the western slopes of the Urals, where beds of Eifelian age are found to

overlie these sandstones. It is a significant fact, that the Eifelian beds of the western Urals have little if anything in common with the typical Eifelian beds of western Europe which are characterized by the fauna with *Calceola sandalina* (Fig. 99). The Eifelian beds of the western Urals are characterized by the typical Boreal coral fauna, with species of *Favosites*, *Alveolites*, *Cyathophyllum*, *Cystiphyllum*, etc. identical with, or closely related to those found in the Onondaga limestones of North America, the eastern representative of which



b *a*

Fig. 99. *Calceola sandalina* Lam., a characteristic index fossil of the Eifelian; *a*, with operculum removed, showing septate calyx; *b*, with operculum in position.

these Uralian limestones are. (See map Fig. 98). The Russian platform, between the Urals and the Baltic region, was not covered by the sea but was the scene of extensive fluvial deposits by rivers from Scandinavia, which was then a part of the old-land of Atlantica. These deposits have produced the lower Baltic sandstone which today preserves the remains of the fishes *Asterolepis*, *Osteolepis*, *Dipterus* etc., which inhabited the rivers of Atlantica in early Middle Devonian time. It was only with the beginning of the Givetian or late Middle Devonian, that the waters of the Ural trough trangressed across these fluvial beds, covering the greater part of the Russian platform, and probably making extensive connections with the seas of central Europe.

The Middle Devonian of central Europe is typically developed in western Germany (Eifel), presenting considerable variation in

facies and faunas in the various regions of its development. The early Middle Devonian sea, which for the most part was confined to the regions south of the fifty-third parallel of north latitude, was characterized especially by *Spirifer cultrijugatus*, the European mutation of *Spirifer acuminatus*, and by *Calceola sandalina*, (Fig. 99) and in the upper part by *Spirifer speciosus* (Fig. 100). In some regions corals were common, but whether these are to be regarded as types which had become residents of the Atlantic waters or whether they represent local emigrants from the Boreal realm cannot be determined at present

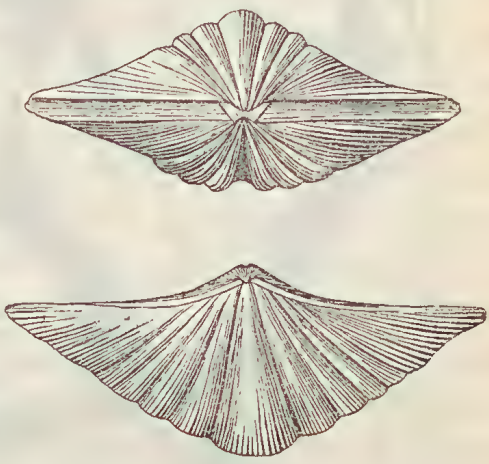


Fig. 100. *Spirifer speciosus*, cardinal and brachial views.

In any case the waters which covered western Europe in Eifelian time, had their chief connection with those of the Atlantic. They may have had some junction with the Boreal waters, but the evidence for this is very inconclusive.

The typical Eifelian fauna or fauna with *Calceola sandalina* (Fig. 99.) is again known in the defiles of the Araxes near the conjunction of the boundaries of Armenia, Russia and Persia. This occurrence indicates the general direction of transgression of the early Middle Devonian sea, which extended probably from the region of the Bosphorus across Asia Minor and Persia, into the heart of southern Asia along the southern border of ancient Caucasia (Fig. 101). That the ancient passage-way along the Hymalayan geosyncline was again open at this time, is shown by the extensive development of the Eifelian fauna at its eastern end, in the Northern Shan States of Burma,

as well as the presence of this fauna in south-western China (Yunnan) and Indo-China.

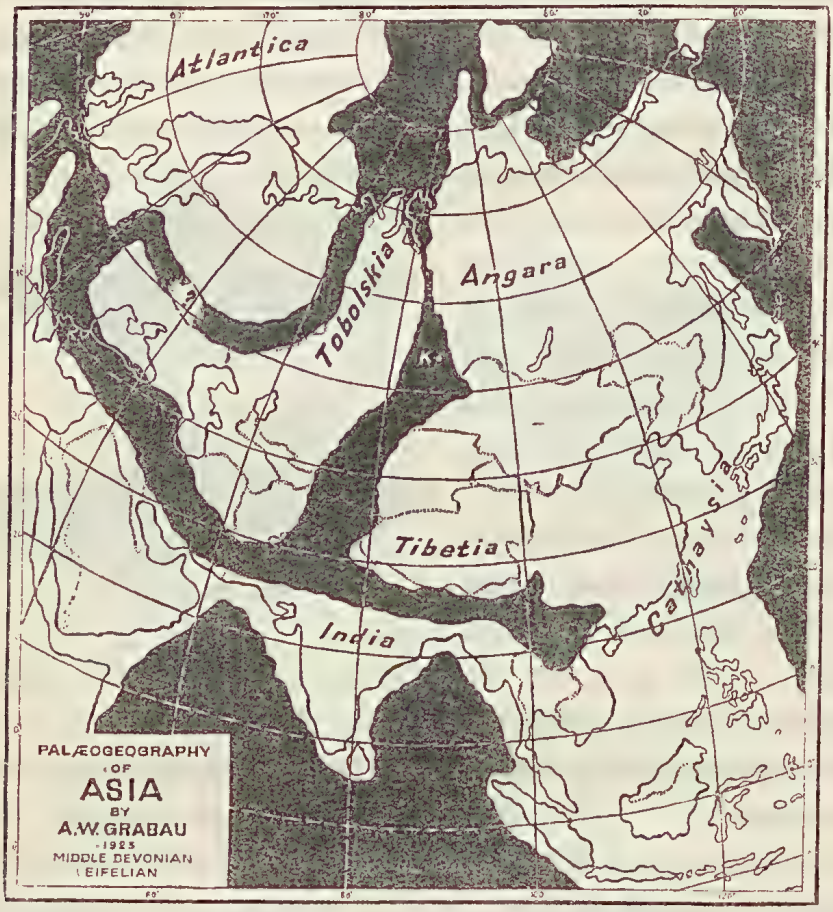


Fig. 101. Palæogeographic map of Asia, showing the distribution of land and sea (black) in early Middle Devonian (Eifelian) time. K.= Kusnezk Basin.

In the Northern Shan States of Burma, Lower Devonian is entirely unknown, though Reed (59) refers to the presence of some trilobites and other forms suggestive of Hercynian affinities, in strata characterized, by *Monograptus* and evidently of Silurian age. Middle Devonian is however well developed, especially at Padaukpin (lat. 22° 6′, long. 96° 40′) where fossils abound in a limestone apparently

interbedded in the main mass of the limestone which forms the Shan Plateau. Corals, bryzoa, and brachiopods are especially abundant in the Padaukpin limestone, while other fossils are comparatively rare. Of the corals, all the species either occur in the Chinese Devonian or are represented by related forms. They and the brachiopods are predominantly of the types characteristic of the Eifelian of Europe, the characteristic *Calceola sandalina* (Fig. 99) being present. There are, however, also many representatives of the Givetian, though the typical *Stringocephalus burtini* (Fig. 103) has not been found. Of the specifically identified species of brachiopods of Burma, 25 per cent. occur in China, and 34 per cent, more are represented by varieties, or closely related species, making a total of 59 percent of the Padaukpin brachiopods, which have so far been found in China (Grabau 19).

We have no conclusive evidence to show that the Eifelian waters transgressed accross central Asia, for the lowest Devonian deposits known from the Tienshan and Kwen-lun Ranges belong to the late Middle Devonian or Kwen-lun transgression. It is true, Muschketow (51) refers to this horizon certain siliceous shales, with intercalated dark limestones, which in eastern Ferghana lie between the Lower Devonian and the Givetian or Stringocephalus beds. These contain a few brachiopods and goniatites, of still undertermined species. It is not impossible however, that these beds may be the basal part of the Givetian, which here may lie disconformably upon the Lower Devonian. Nevertheless, we must assume that the Eifelian sea did send an arm northward, at least as far as the Kusnezk basin (abt. lat. 54° N., long. 88° E.), in the Siberian government of Tomsk, for from this region a very rich Middle Devonian fauna has been described by von Peetz (55). Both the *Calceola sandalina* and the *Stringocephalus burtini* stages are recognized, the former comprising 60 species, and containing nearly all the European species found in the Padaukpin beds of Burma, while several Russian or

Uralian forms, and about half a dozen new species are present. The presence of the Boreal species suggests a connection with that sea but this was probably slight as the number of species is so small.

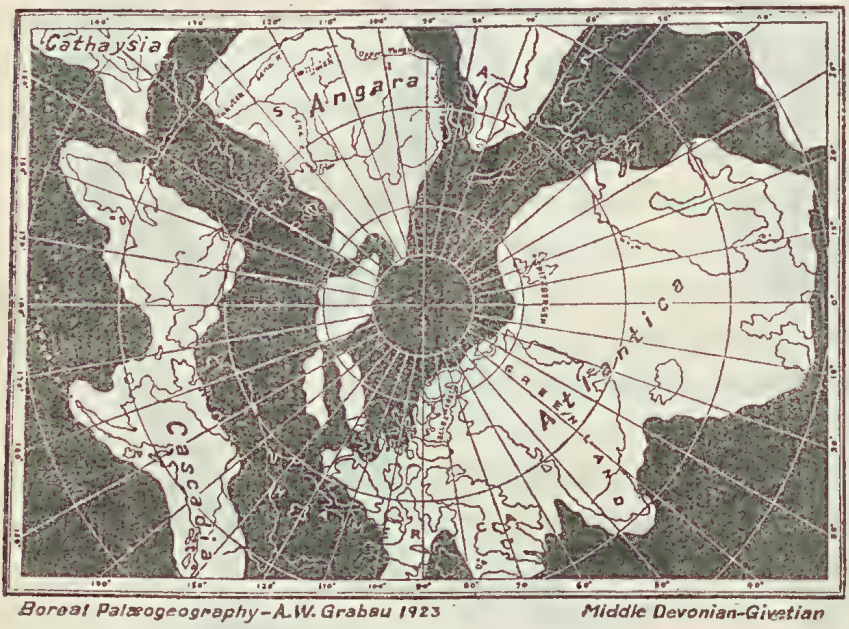


Fig. 102. Palæogeographic map of the present north polar region, showing the marine waters (black) which probably crossed it in later Middle Devonian (Givetian-Erian) time, and the probable routes of migration of the faunas between America and Eur-Asia.

Erian or Givetian Epoch. The second half of the Middle Devonian, which in Europe is known as the Givetian and in America as the Erian, witnessed a decided change in the arrangement of lands and seas, in all parts of the present northern hemisphere. There are good reasons for believing that the Boreal waters, which had furnished the main source of the faunal elements of the Onondaga beds of North America, at this time assumed a minor importance, if the connection had not become entirely severed (Fig. 102), for while the coral element continues in the Hamilton fauna, it is now an endemic element, and the brachiopod element is to a large extent of Atlantic origin.

Indeed the typical Hamilton fauna of North America with *Spirifer mucronatus* and *Tropidoleptus carinatus* must be regarded as an endemic fauna, continuing in the Atlantic Ocean until far into Upper Devonian times. In the central region (Michigan, Ontario, etc.) a provincial fauna arose, under conditions of isolation from a cut-off remnant of the typical Hamilton fauna. This fauna, known as the Traverse fauna, contains a considerable foreign element, which is more purely developed in Iowa, Manitoba, and Alaska. This is the invading Givetian fauna of Europe, with *Stringocephalus burtini* (Fig. 103), *Schizophoria striatula*, and other forms, strange to the Atlantic Hamilton type, or Erian fauna.

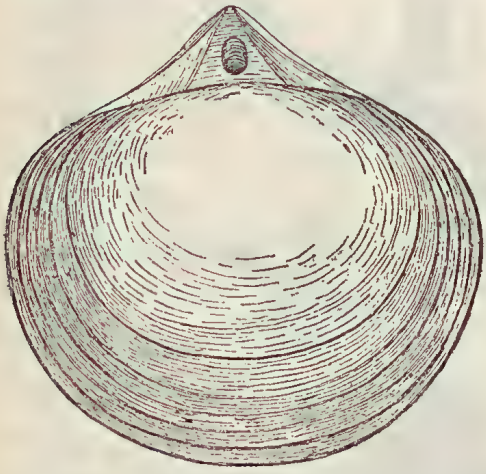


Fig. 103. *Stringocephalus burtini*, the index-fossil of the Givetian.

While thus in America the Boreal seas were virtually divorced from the interior waters, these now entering into closer relations with the Atlantic waters on the one hand and the Eur-Asian seas on the other, the conditions were the reverse in Europe. The Boreal sea, which had only occupied the Ural geosyncline but not the Russian platform in Eifelian time, now spread across the latter, converting it into a vast inland sea (Fig. 104).

Wherever the fluvial deposits of the Eifelian with their fish remains had been deposited, these were now covered by the sediments of the Givetian sea, whereas in regions not reached by the fluvial deposits, the Givetian sediments rest directly upon the older rocks. Thus in the vicinity of Lake Onega, these beds rest transgressively

upon the Pre-Cambrian rocks of the Fenno-Scandian shield.

For the most part this Russian sea had only minor connections with the rest of Europe through the Polish channel, between the terrestial deposits on the north and the Caucasian old-land on the

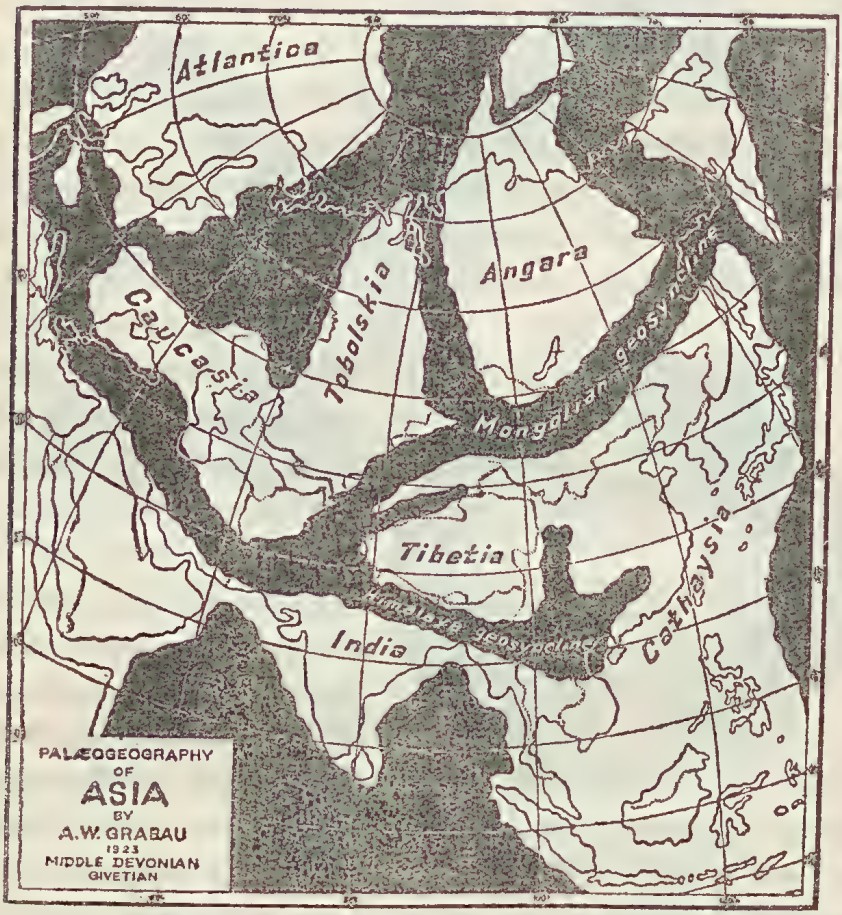


Fig. 104. Palæogeographic map of Asia, showing the probable distribution of land and sea (black) in later Middle Devonian (Givetian) time and the main geosynclines.

south; its leading form was *Spirifer anossofi* (Fig. 105), a species which has been erroneously reported from the Chinese Devonian. With it, in the Ural region, occurs *Stringocephalus burtini* (Fig. 103), and *Schizophoria striatula* (Fig. 137).

The place of origin or nativity of *Stringocephalus* presents an interesting problem. The genus appears suddenly in European waters without any apparent predecessors. It cannot be regarded as of Atlantic origin, because the genus is wholly foreign to the typical Hamilton fauna which, according to all indications, was endemic in that water body. Its appearance in Asia and western North America is clearly the result of migration, while its sporadic occurrence in the expanded Boreal waters of the Russian basin, scarcely admits of the assumption of a Boreal origin, but suggests immigration through the Polish channel, in the deposits of which it is well represented. This suggests that it arose in some European basin from a still unknown Eifelian ancestor.

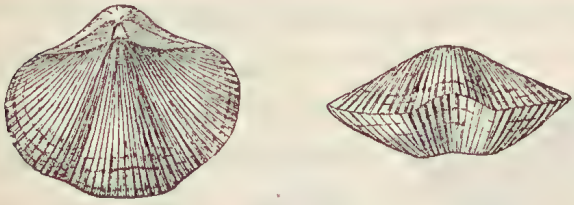


Fig. 105. *Spirifer anossofi* Middle Devonian (Givetian).

It is still a matter of doubt, to what extent the Givetian is represented in the Altai basin of Asiatic Russia. The Middle Devonian strata found in the Salair mountains, consist of shales and limestones with the Boreal coral fauna, but whether these waters had any connection with the seas which now began to cover central Asia is less certain. Such connection has, however, been represented on the map.

The pronounced marine transgression which affected central Asia in Givetian time has come to be known as the Kwen-Lun transgression. It was then that the sites of the present Tianshan and Kwen-Lun mountains were first inundated, these late Middle Devonian beds resting directly upon the ancient crystallines.

There is no evidence to show that this transgression extended into the Nanshan region and thence into the Chinese or Cathaysian basin; the evidence available points to the invasion of the Chinese

basin along the southern or Himalayan route. On the other hand, the occurrence in the Minuzinsk region of Siberia, within the geosynclines which enclosed the Angara-land, of *Spirifer cheehiel* (Fig. 106) a typical Chinese form, together with *Spirifer anossofi* (Fig. 105), a typical Boreal form, indicates that connection had been established between these geosynclines and the more southern waters.

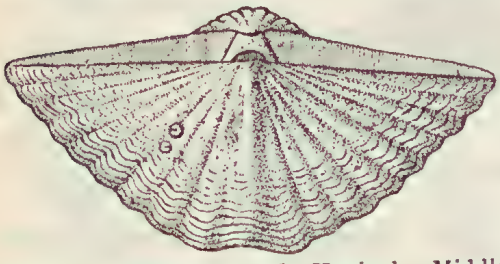


Fig. 106. *Spirifer cheehiel* de Koninck. Middle Devonian (Givetian).

From gray limestone on the River Beja in the Minuzinsk region, a rich Middle Devonian fauna has been obtained, in which the presence of several Chinese species is an interesting feature (Stuckenberg 65). The species identified, include the brachiopods: *Crania obsoleta* Goldf., *Strophalosia productoides* Murch., *Orthotetes crenistria* Phill., *Atrypa reticularis* Linn., *Spirifer cheehiel* de Kon., *S. undiferus* Roem., *Athyris concentrica* v. Buch, *Emanuella takwanensis* (Kayser), and in addition, *Spirorbis omphalodes* Goldf., *Cornulites epithonia* Goldf., *Aulopora repens* Knorr, *A. tubæformis* Goldf., *Monticulipora fibrosa* Goldf., and *M. parasitica* Kayser. Besides these, there are three new species of *Spirifer* (*S. martianofi*, *S. kayseri*, and *S. smidti*), two of *Rhynchonelloids* and a *Pterinea*, besides several specifically unidentified forms. The same fauna is indicated in two other localities.

In the region near Tomsk, on the Yaia and elsewhere in that section of Siberia, Middle Devonian shales and limestones occur, enclosing *Spirifer undiferus* Roem., *S. cheehiel* de Kon. (Fig. 106), *Strophomena interstrialis* Phill., *Strophalosia productoides* Murch., *Cyathophyllum hexagonum* Goldf., *Favosites cervicornis* Blainv., *Actinostroma clathratum* Goldf., etc. In places these beds are strongly metamorphosed, the limestones becoming marble and the siliceous

beds being altered into quartzites. They are succeeded by shales and limestones with a rich Upper Devonian fauna (Krasnopolsky 32). Beds regarded as of Middle Devonian age are also reported from the Kirghiz steppes, where they are represented by limestones which rarely contain fossils, and which are subordinate to quartzites and schists. From the limestones the following species have been obtained: *Leptæna rhomboidalis* Wahlb. var. *analoga* Phill., *Proëtus* cf. *rana* Hall, *Proetus* cf. *macrocephalus* Hall, *Favosites goldfussi* d'Orb. They are succeeded by Upper Devonian rocks which are very fossiliferous.

Recently the Third Asiatic Expedition has brought back material from the Mongolian geosyncline which indicates the presence there, of Devonian strata. These are also known in the Nertchinsk Mts. near the Transbaikal-Manchurian border (abt. long. 115°-120° E. lat. 50°-53° N.). Still farther east, Ivanow (26) has found Devonian beds in the Amur country, to the north-west of Khabarowsk, especially on the upper branches of the Kur and Unma (Ounma) rivers (lat. 50°) and in the basin of the Grand Bira (lat. 49°). More recently Ahnert has found Devonian strata at Erh-Tsin-Tsian-Sze in Manchuria and P. Pazausky in the Evaron lake district on the lower Amur (abt. lat. 51°, long. 137°), but the details of these are still lacking, and it is not known whether they include Middle Devonian.* The occurrence of Devonian strata on the west coast of Okhotsk sea, near Ayan (abt. lat. 56°30' N.) is well known, but again it is not ascertained whether or not these include Middle Devonian beds.

Beyond these points, the further extent of the ancient waterways is purely conjectural, nor is it known whether a connection existed with the Pacific Ocean of the period, though this is not unlikely. The probabilities are that an arm extended north between

*In accordance with these recent discoveries, the southern border of the Mongolian geosyncline should be drawn farther south in the eastern region, than is shown upon the Palæogeographic map.

longitudes 140 and 160 degrees, until it met the extension of those waters which then covered Alaska. That a pathway of this kind existed, is shown by the abundant development of the Givetian elements of the Middle Devonian fauna in the so-called Dakota sea of western North America, where the coral elements of this fauna, as well as a number of its characteristic brachiopods, have a wide distribution, while *Stringocephalus burtini* (Fig. 103), the index fossil of the Givetian is found as far south as Manitoba.

The Givetian fauna is well developed in the Middle Devonian rocks of China, this division being more fully represented there than the Eifelian. At present *Stringocephalus* is known only from eastern Yunnan, but other members of the fauna are quite extensively distributed. The details will be given below.

UPPER DEVONIAN.

The peculiar distinction of oceanic basins and interior seas which we have seen to have been in existence in later Middle Devonian time, persisted into the Upper Devonian, where, however, the progress of geographical development became more complicated by the progressive increase of the activities of the rivers of the several land areas, and a consequent wide extension of shallow water clastic, and eventually of continental deposits. According to all the available evidence, the waters of the Atlantic continued to remain the home of the little modified Erian type of fauna, for we find that it re-enters the interior of North America from the Atlantic at various times in the Upper Devonian. Black mud sediments, however, brought by rivers from the broad expanses of southern North America, had begun to be a marked feature of the southern border of the interior seas, while alluvial fans and deltas built by streams from Appalachia, began to encroach upon them from the east.

Senecan or Frasnian Epoch. Almost from the opening of the period, the combined work of the waves and of the mud-bearing

rivers from the south had affected the virtual separation of the greater part of the interior seas of North America from the Appalachian geosyncline, while mud-barriers in like manner effected a separation between the central and the Dakota sea, where the Eur-Asian fauna continued to exist. Within the central waters thus separated, a new fauna arose by modification under isolation of the Hamilton or Erian fauna which had remained in that basin, but because of the effective barriers on the east, was prevented from intercrossing with the normal Erian fauna which still continued to exist in the Appalachian geosyncline and in the Atlantic waters.

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The first of these newly arisen faunas was that of the *Tully limestone* of New York, but this fauna also included some emigrants from the Dakota sea, into which they had wandered from Asiatic waters. Foremost among these foreign elements were *Hypothyridina cuboides* and *Schizophoria striatula* (*S. tulliensis*). (Grabau 16).

A somewhat younger fauna, developed in this region under similar conditions, was that of the Ithaca shales of the Portage group. This fauna eventually mingled with the unmodified Hamilton fauna of the Appalachian trough on the submergence of the intervening barrier (Grabau 17). Meanwhile an entirely new fauna arrived in this basin with startling suddenness. It was a fauna composed of goniatites, pelecypods (cardioconchs), and pteropods, and was apparently of a pelagic habitat. This fauna, which in America is known as the Naples fauna, existed side by side with the contemporaneous Ithaca fauna of the more eastern part of the basin, from which it was separated by no barrier, but with which it did not intermingle. It had another contemporary in the fauna of the Dakota sea which was continuous with the waters of eastern Asia, but separated from the interior American sea by the old-land of Mackenzia, the continuation of Angara-land, and by mud deltas built by rivers from the south, and now preserved as black Devonian shales (Antrim shales,

etc). The goniatite fauna is well known in Europe, many of the species there being identical with those found in North America. From the leading member of this fauna, *Goniatites (Manticoceras) intumescens* (Fig. 107), this fauna is generally spoken of as the *Intumescens fauna*. It is known from the Urals and the Timan range of northern Russia and from many districts in western Europe where it constitutes a phase of the Frasnian, as the early Upper Devonian of Europe is called. (See map Fig. 108).

Fig. 107. *Manticoceras intumescens*. Early Upper Devonian (Frasnian). Boreal fauna.

Apparently this fauna did not enter, to any great extent, the south European regions which formed the passage-way to Asia, for we do not recognize it anywhere in the known Asiatic Upper Devonian deposits. This would also argue that the Altai extension of the Boreal sea was no longer an open passage-way as it appears to have been in Middle Devonian time. This indeed we find indicated by the nature of the sediments and their faunas in the Altai region. Those of Tomsk, Kusnezk, Irtysch and near Bajanaul, are marine sediments with a normal Asiatic fauna, while west of Bajanaul are the Akmolinsk fluviatile deposits of this period and east of Kusnezk the red sandstones and gypsum deposits of Minuzinsk, etc. In the Salair mountains, Upper Devonian seems to be entirely absent. It is thus apparent that the Middle Devonian waters became much contracted in Upper Devonian time and those which remained were disconnected from the Boreal sea (Fig. 109).

We are thus forced to the obvious conclusion that the Intu-

mescens fauna was primarily at home in the Boreal realm, thence extending its migrations into interior North America on the one hand, and into western Europe on the other. There is no other possible center of distribution for this fauna so far as our knowledge of it is concerned, and we are forced to the further conclusion that it originated in the Boreal realm, probably after the complete extinction there of the early Middle Devonian coral fauna, which, however, survived in European, Asiatic and west American waters into Upper Devonian time.

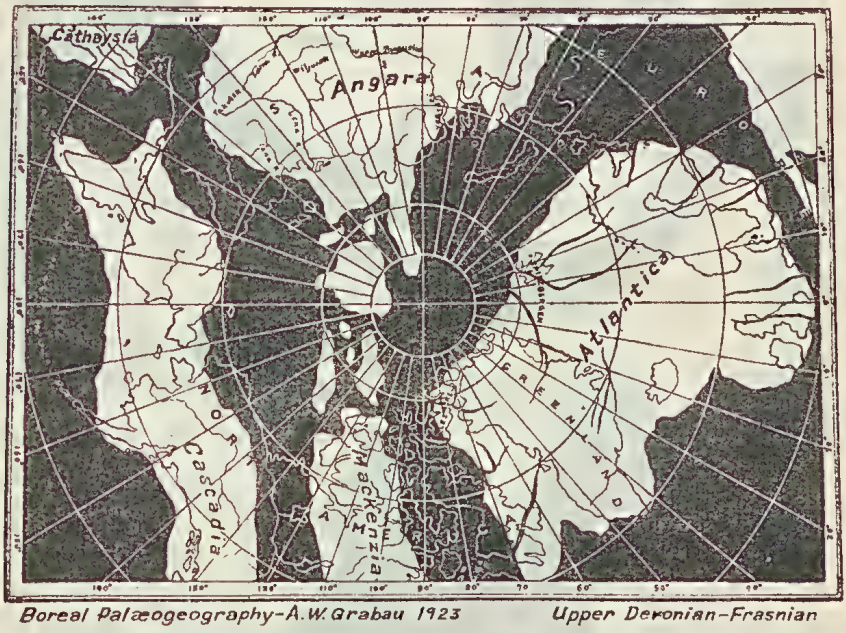

Fig. 108. Palæogeographic map of the present north polar region, showing the probable water-ways (black) which crossed it in early Upper Devonian (Frasnian-Senecan) time, and the routes of migration of the faunas between America and Eur-Asia.

Existing side by side with the goniatite fauna of the Boreal province, was the normal Upper Devonian fauna, which had arisen by modification from the preceding Middle Devonian fauna in partly circumscribed basins upon the European continent, as the Ithaca fauna had arisen in America. This is the typical Frasnian fauna, in which *Spirifer verneuili* Murch. forms a leading element. This name

is applied to a group of transverse *Spirifers*, the fold and sinus of which show a definite mode of costation and which in China is represented by numerous mutations referred to collectively as *Sp. chinensis* (Fig. 110). Appearing in the late Middle Devonian (Give-

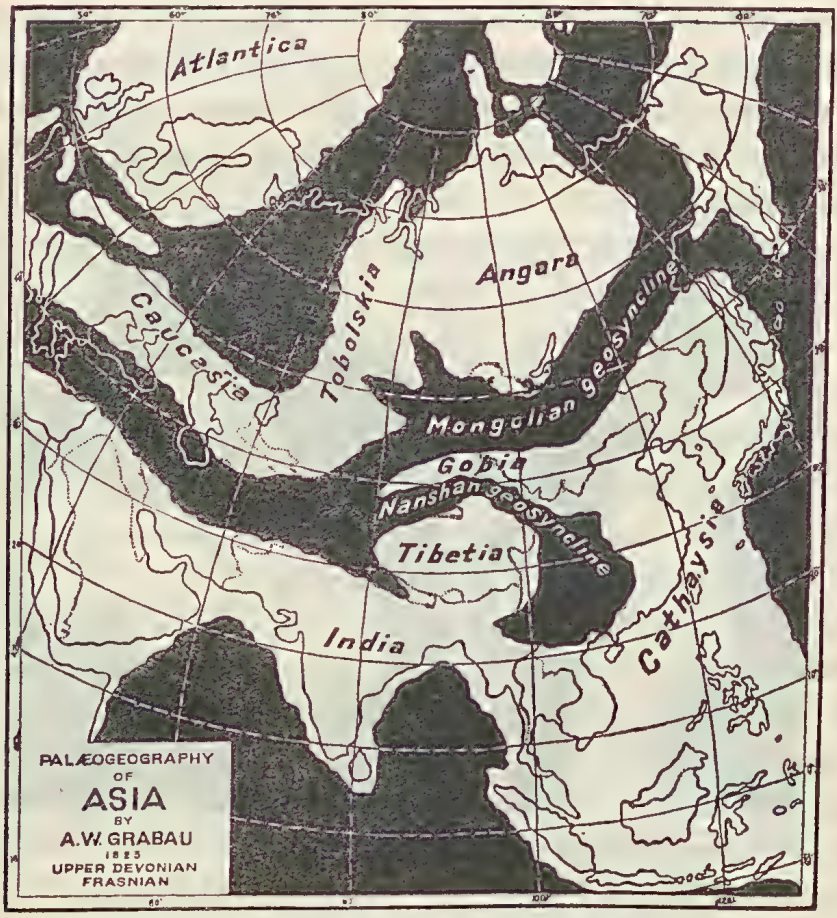

Fig. 109. Palæogeographic map of Asia, showing the probable extent of land and sea (black) in early Upper Devonian (Frasnian) time, and the principal geosynclines of the epoch.

tian) in association with *Stringocephalus* in Belgium, and developing numerous mutations, this specific group quickly spread over Europe and Asia. Associated with it was the shorter thicker *Sp. archiaci* (Fig 111) with high hinge area, and, in the west European region, *Cyrtiopsis murchisonianus*. Almost everywhere too, the earlier beds

are characterized by the robust *Hypothyridina cuboides* (Fig. 112) which is another characteristic and wide-spread species. Corals too, are not uncommon in this horizon and in some sections, as in Poland (Kielce), they form reefs. The most abundantly represented genera are compound Cyathophyllidæ, especially *Phillipsastræa* and *Pachyphyllum*, forms which have direct ancestors in the Middle Devonian.

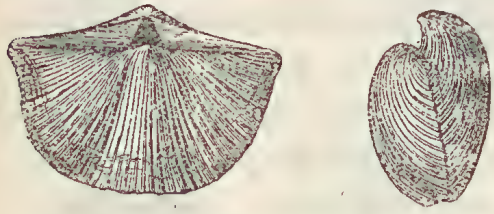

Fig. 110. *Spirifer chinensis* Grabau. Mut. ∝ Upper Devonian of China.

We are able to trace the pathway of migration of the Frasnian fauna across southern Asia, from its known occurrences at a number of localities. Thus it has been reported from rocks on the Bosphorus, and from deposits which enter into the structure of the Anti-Taurus range in southern Asia Minor. (Penecke 57). It is also reported from the Giaur Dagh in northern Syria. Again it is known from strata exposed in the gorge of the Araxes river near the conjunction of the Russian, Armenian, and Persian borders (14). In Persia itself, it has been found in the central Elburz range, and near Teheran, some distance south of the Caspian Sea, near Asterabad east of the southern end of this sea, (Frech and Arthaber 14), and in the Mashhed district (Reed 60). Finally it has been recorded from the Hindukush mountains in eastern Afghanistan, from eastern Ferghana, and elsewhere in central Asia. These occurrences will be noted more fully below. Upper Devonian has also been recorded from the central Tianshan and its presence is known in the Nan-Shan ranges, where in the Richthofen mountains *Sp. anossofi*, *Sp. elegans*, and *Rhynchonella aliensis* have

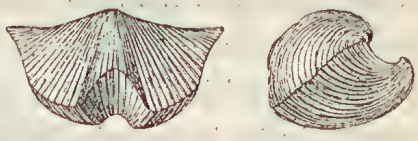

Fig. 111. *Spirifer archiaci* de Vern. Upper Devonian (Frasnian).

been obtained (Obrutschew). Its extensive development in the strata which enter into the southern Tsingling folds of China, as well as its presence elsewhere in China, indicates that the Kwen-Lun-Nan-Shan geosyncline was in general the line of passage by which this fauna entered Chinese waters (Fig. 109). That it did not enter the Chinese basin by the southern or Himalayan geosyncline, which, as we have seen was the path-way of immigration of the Middle Devonian fauna, is shown by the total absence of the Frasnian or any other typical Upper Devonian fauna in the strata of the eastern Himalayas or of Burma, as well as by its incomplete development in Yunnan.

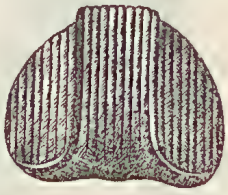

Fig. 112.
Hypothyridina cuboides Frontview. Upper Devonian (Frasnian).

The trans-Asiatic passageway along the Mongolian and Trans-Baikal geosynclines was likewise open, for we find this fauna well developed in the Altai region of southern Siberia and it has again been obtained from a series of alternating shale and limestone beds exposed on the southern coast of Ayan Bay in the sea of Okhotsk (Diener 4). In these beds *Spirifer verneuili*, and *Spirifer mesacostalis* were found associated with indeterminable species of *Athyris*, and *Orthis*, and of trilobites (*Proetus*) and gastropods (*Phanerotinus*, *Euomphalus etc.*).

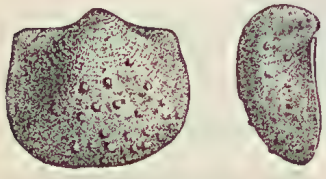

Fig. 113.
Productella subaculeata Murch. late Middle and early Upper Devonian.

Direct connection with Pacific waters is indicated by the finding by Gottsche, of a specimen of *Spirifer verneuili* in the province of Ise in Japan.

Finally the connection with the northern sea, approximately as shown upon the map (Fig. 109), is indicated by the discovery on the New Siberian Islands, of strata carrying a brachiopod fauna of Upper Devonian aspect (von Toll, 72). According to provisional determinations, the fauna includes a mixture

of European (*Spirifer elegans*, *Sp. anossofi*) and west American forms (*Spirifer whitneyi*, *Schizophoria iowensis*, *Productella hallana*, etc.).

The presence of this Eur-Asian fauna in the "Dakota Sea" of western North America has already been referred to, and we have

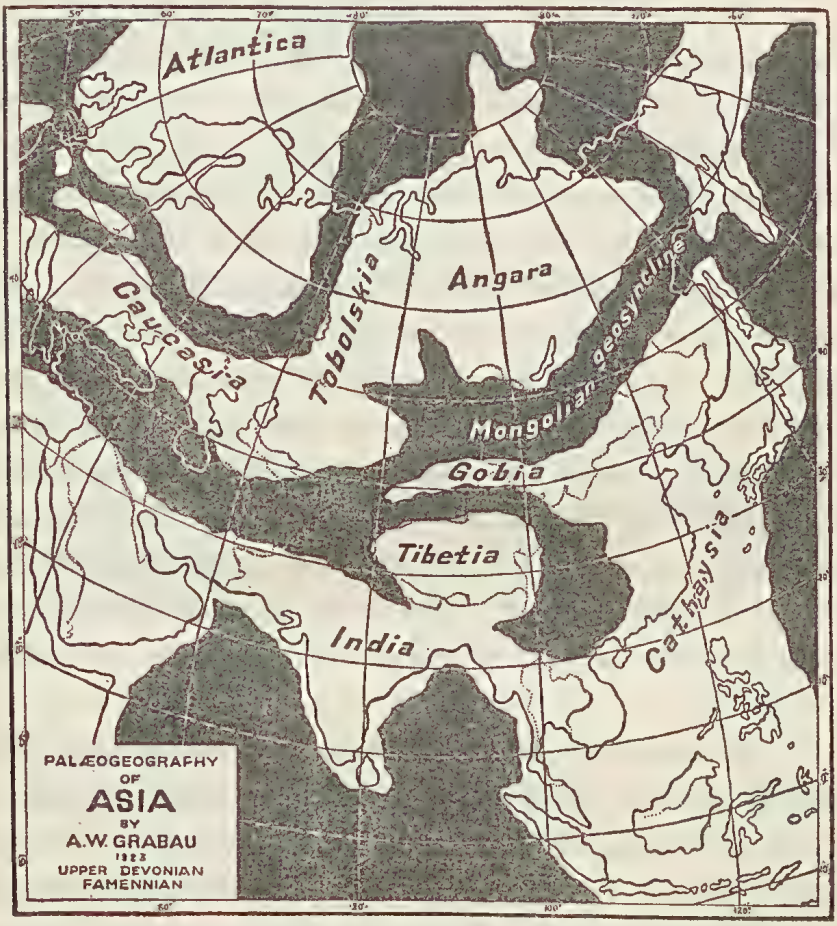

Fig. 114. Palæogeographic map of Asia, showing the probable distribution of land and sea (black) in later Upper Devonian (Famennian) time.

seen that *Hypothyridina cuboides* reached what is now central New York (Tully limestone), while the fauna as a whole is widely distributed from Alaska to Iowa, extending southward into Nevada etc.

From its relationship to Chinese geology this transgression of the sea across Asia at the beginning of Frasnian time, may be called

the *Nanshan transgression*, in contra-distinction to the earlier Kwen-Lun transgression of Bogdanowitsch which passed China by on the north, though reaching it through the southern passage (Himalayan geosyncline).

Chautauquan or Famennian Epoch. The final epoch of the Upper Devonian, the Chautauquan of America or the Famennian of Europe, began after the expansion of the epeiric seas had come to an end, and a negative movement was inaugurated by the rising of the old-lands, and the consequent wide distribution of the sands and muds brought by the rejuvenated rivers from these rising land masses. Because of the prevalence of semi-arid climatic conditions, these sands were thoroughly oxidized, as are those of the Yangtze and Huang-ho of China today, and just as these delta deposits are pushing back the sea-margin today, so in Devonian times the great yellow delta plains of eastern North America and western Europe pushed back the sea margins, the one to the west, the other to the east (Map, Fig. 114). These sands are no longer yellow, because in the course of time the iron hydrate which gave them that color, has lost its water, and become a red oxide of iron. Consequently these strata are red-beds today.

In North America, these continental beds are known as the Catskill sandstones. They have their maximum thickness (5000 feet or more) in the Appalachian trough, thinning away westward by the failure of their lower members, which are however replaced by marine shales and sands, these constituting the contemporaneous Chemung formation. This relationship is known as *replacing overlap*, the continental beds gradually and progressively replacing the marine beds (Grabau 15). The two series are thus separated by a diagonal line as shown in the following diagram (Fig. 115), where it is seen that the marine Chemung beds are present in full force in the west, while the continental beds are alone present in the east. Between the

two localities a varying thickness of marine beds is overlain by continental beds, the thickness of which varies in the opposite direction.

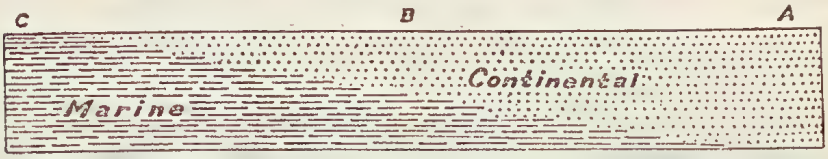

Fig. 115. Diagram illustrating the phenomenon of *replacing overlap*. The continental beds on the east progressively push back the marine beds on the west, overlapping and replacing them. At C, the beds are all marine, at A, all non-marine. At B, the lower half is marine, the upper half non-marine.

The Chemung fauna of North America is primarily a derivative of the Ithaca fauna of the preceding epoch, as shown by J. M. Clarke, but with additions from the Frasnian elements of Europe which occupied the western or Dakotan sea of North America. The most significant of these new elements is *Spirifer disjunctus* which, with its own series of mutations, represents a further modification of *S. verneuili* of Europe.

This was a period of contracting seas and shoaling waters over central North America and of wide-spread deposition of terrigenous clastics. These were partly derived from the old-land of Appalachia, partly from the low-lands on the south (Mississippia), where slow disintegration was in progress. These latter deposits were chiefly black muds, and they have become an important source of petroleum and natural gas in North America. The connecting passage between the central North American sea and the Boreal region, along which migrated the Intumescens fauna in the preceding epoch, was now closed by elevation and continental deposits, and after a while the Atlantic passageway was also closed by extensive deposits of subaërial sands, so that the interior sea became eventually a nearly isolated body with connections only with the western or Dakotan sea, in which the Eur-Asian fauna continued to flourish to the last. The

Boreal sea on the other hand seems to have contracted into a nearly, if not quite, enclosed mediterranean type of sea, in which a new fauna was slowly developing under the fostering conditions of isolation (Fig. 116), this fauna reappearing later in North America as the early Mississippian fauna.

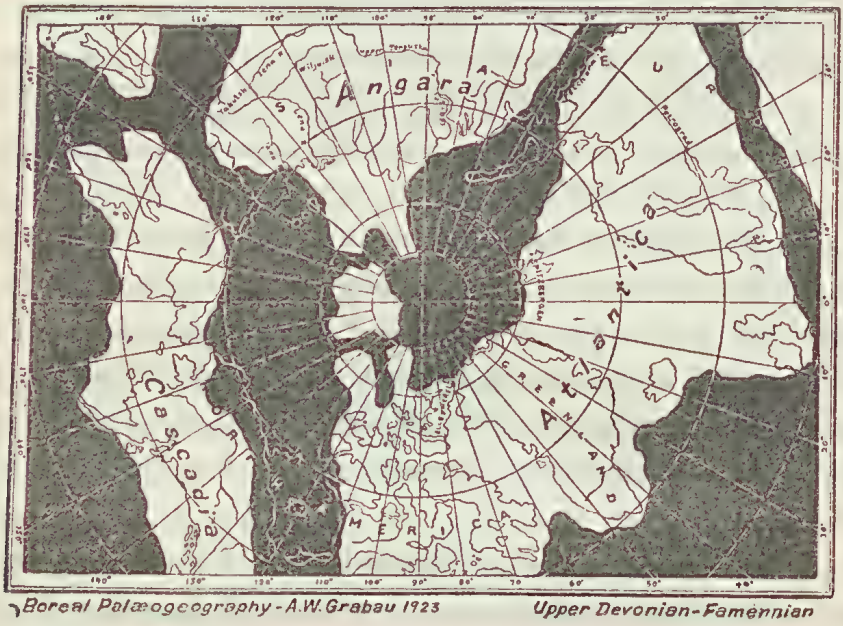

Fig. 116 Palæogeographic map of the present north polar regions, showing the marine basins (black) which probably existed there in late Upper Devonian (Famennian-Chautauquan) time and the routes of migration of the faunas between Asia and America.

If we now return to Europe, we find that the Famennian or latest Upper Devonian period was also one of contracting seas. The Russian platform began to re-emerge by the extension of the great sand deltas which were washed by the rivers from the Fennoscandian portion of the old-land of Atlantica. This formed a deposit essentially similar to that which characterized the early Middle Devonian (Eifelian) epoch, and like that, enclosed the remains of fishes (*Holoptychius nobilissimus*, *Bothriolepis*, *Dendrodus*, *Cricodus*, *Coccosteus*, etc.) which, moreover, are mostly identical with the species found in the

upper Old Red Sandstone of Great Britain, a contemporary deposit of this type. These continental sandy deposits of the Upper Devonian now constitute the Upper Baltic sandstone (Fig. 114).

These deposits probably had the same replacing relation to the marine series that is found to exist between the Catskill and Chemung. The marine Famennian continued in the Uralian geosyncline, being found in the Urals as far south as Orenburg. It is highly probable that this southern end of the geosyncline was connected by a water-way with the west European basin, as in shown by the similarity of part of the Famennian fauna of the Ural region to that of west Europe. The same continental types of deposits represent the Upper Devonian on Bear Island, between Scandinavia and Spitzbergen. On this much eroded fault-block-remnant of the old Arctic land mass, the marine Hecklahook formation (Black-River Ordovician and probably some early Silurian) is unconformably overlain by the Ursa sandstone which begins with a basal conglomerate, and higher up encloses black shales and even a coal bed 1 meter thick. The sandstones enclose remains of *Holoptychius*, and carry the remnants of a rich flora, most frequent among which are those of *Archæopteris hibernica* and *A. fimbriata* Nath., *Bothrodendron kiltorkense* Haughton, and *Pseudobornia ursina* Nath. After further folding and erosion during Dinantian time, these beds were unconformably succeeded by Moscovian and Uralian marine beds.

In Spitzbergen two phases of the Old Red Sandstone are represented, an earlier with *Pteraspis* and *Cephalaspis* and a younger, more shaly series with *Holoptychius*. The Ursa flora is not found. In some beds, however, (Grey Hook), molluskan remains have been found (*Avicula*, *Nathorstella*, *Palæanodonta*) which are probably brackish-water types, and indicate the nearness of the Boreal sea. Similar upper Old Red Sandstones with *Holoptychius nobilissimus* and *Asterolepis* are found on the east coast of Greenland, while on Elles-

mereland, marine beds with *Sp. verneuili* are followed by continental beds with *Holoptychius* and plant remains (*Lyginodendron sverdrupi*, *Archæopteris archetypus*, *A. fissilis*, *Sphenopteridium keilhavi*).

That the contraction of the seas was also felt within the west European basins, is shown by the succession in the Namur basin of Belgium, where marine Frasnian is followed by the micaceous Condroz sands, alternating with red and green clays. Marine beds with shells of *Cucullæa*, *Agelacrinus* and *Dictyospongidæ*, alternate with non-marine beds carrying plant remains (*Achæopteris*, *Sphenopteris*, *Lepidodendron*) or fish remains (*Holoptychius*, *Asterolepis*, *Dipterus*). A similar character is seen farther west in Pas-de-Calais, France, where the Ferques limestone with a rich marine fauna of Frasnian type, is followed by the Condroz sandstone series. These sands were spread by rivers which flowed from the land surface which now forms the bottom of the North Sea.

The marine phase of the highest Devonian (Famennian) of Europe still retains some features of the Frasnian, but new types have appeared, some of which are suggestive of Dinantian affinities. Among the characteristic species in the Famennian of the Ardennes, are *Spirifer verneuili*, *Cyrtiopsis murchisonianus* and many *Rhynchonellas*, especially *R. omaliusi*, *R. acuminata*, *R. dumonti*, and *R. letiensis*. *Athyris roissyi* and *Orthotetes crenistria* which, with *R. acuminata*, are characteristic of the Dinantian, also make their first appearance.

Another and very distinct fauna is found in the Famennian beds of certain sections of western Europe. In the region east of the Rhine (Nassau, etc.) the basal beds are characterized by a new assemblage of the goniatites not known from the lower beds. These are the close-coiled *Chiloceras* (*C. curvispina*, *C. verneuili*. *C. sacculus*, *C. acutus*) and species of *Tornoceras* (*T. planidorsatum*, *T. acutum*,

T. haugi), *Aganides præcursor*, etc. Succeeding beds are rich in species of *Clymenias* (*Clymenia*, *Oxyclymenia Pseudoclymenia*, *Gonioclymenia* (Fig. 117), etc.

This Clymenia fauna is widely distributed in the north European region, extending from Devonshire England and western France (Finisterre), south to the Pyrenees, and east along the Alps through Austria (Gratz), Silesia and Poland to the Russian border. It is also found to the north of the landmass formed by the elevation of the Bohemian region, where Upper Devonian is unrepresented by marine beds. Between Poland and the southern Urals, no record of the existence of this fauna is known, but it is probably present in some of the beds now covered by younger formations. This is indicated by the fact that the *Clymenia* fauna is well developed in the rocks of the Ural geosyncline, and as southern Russia appears to be the only possible line of connection, it is so indicated upon the map (Fig. 114). Thus the *Clymenia* fauna occupied the seas which lay along the periphery of the growing fan of river deposits that was spread from Atlantica over the Russian plain. The presence in the Ural geosyncline of this *Clymenia* fauna, which like its predecessor, the Intumescens fauna, was probably one primarily pelagic, suggests that it too originated in the Boreal realm, whence it spread mainly over northern Europe. It is, however, not unknown in North America, for in the Three Forks shales of Montana, within the Dakotan sea, its representative has been found (Raymond). Besides *Platyclymenia americana*, a close relative of *Clymenia annulata* of Europe, and *P. polypleura*, the fauna includes the goniatites *Pro-*

Fig. 117.
Clymenia (Gonioclymenia) uhligi Upper Devonian (Famennian). Boreal province.

lobites simplex and *Tornoceras* (*T. crebriseptum* and *T. douglassi*), and a number of brachiopods, most common among which is *Spirifer whitneyi*. These late Devonian beds are disconformably succeeded by early Mississippian (Louisiana) sandstones, followed in turn by the great Madison limestone, also of Mississippian age. This fauna is unknown from central and eastern North America.

If then the Clymenia fauna originated in the Boreal sea, we can readily understand that some such conditions as those depicted on the palæogeographic map (Fig. 116) were responsible for the unequal migrations. If it did not originate in the Boreal sea, it must have been of Atlantic origin, as suggested by Schuchert. In that case it migrated across Europe through the Ural geosyncline, and through the Boreal sea into the American waters. As we have seen, however, the Atlantic connection was still in force in Chemung time, and yet *Clymenia* is unknown in these deposits, which would hardly have been the case had it been an Atlantic pelagic form. On the other hand, the fine development of the *Clymenia* fauna at Beni-Abbas in the Oran Sahara of north Africa, might indicate that it belonged to the Atlantic fauna. Though more than 1,500 km. removed from the nearest locality in Europe, that of Montagne Noire in southern France, the association of species is exactly the same as in the classical European localities. With the exception of this north African occurrence, the *Clymenia* fauna seems to be unknown in the southern water-way, nor is it known from any deposits in Asia. Apparently migration in that direction was prevented in some way, though future discoveries may show its actual presence in Asia. Possibly the vigorously developing Chinese Devonian fauna, produced antagonistic elements, which kept out the European migrants. For, under the fostering influence of isolation, there was produced in China a great series of new mutations, which then wandered into extra-Chinese waters, and gave the tone to the Asiatic Upper Devonian fauna.

UPPER DEVONIAN OF ASIA.

Asia Minor. Upper Devonian is well developed in southern Asia Minor, being the chief representative of the Devonian in the Antitaurus, though some Middle Devonian may also occur (Penecke 57, Broili 5). At Hadjin (Hadschin), corals are well represented, including the genera *Thamnophyllum*, *Cyathophyllum* (*C. cæspitosum* Goldf., *C. minus* Roem., *C. darwini* Frech, *C. marmini* E. & H., *C. sedgwicki* E. & H.), *Phillipsastræa*, *Darwinia*, *Favosites*, *Pachypora* (*P. cristata* Blum., *P. reticulata* Blainv.), *Striatopora* (*S. subæqualis* E. & H., *S. vermicularis* McCoy), and *Cœnites*. Among the brachiopods such characteristic forms as *Schizophoria striatula*, *Spirifer disjunctus*, *S. archiaci*, *Atryppa reticularis*, *A. aspera*, *Hypothyridina cuboides*, and *Rhynchonella pleurodon* are noted.

Persia. In northern Persia the upper Devonian is represented near Teheran and Asterabad by beds carrying a west European fauna. Aside from the trilobite *Cryphæus supradevonicus* and the pteropod *Tentaculites tietzii*, the fauna consists of brachiopods including *Productus fallax*, *Liorhynchus crenulatus*, *Rhynchonella letiensis*, *R. gouthieri*, *Spirifer verneuili*, *S. archiaci*, and *S. anossofi*. The beds underlie the Carboniferous concordantly. While some of the most typical Famennian species of the Ardennes are here present, the occurrence of the Frasnian *Sp. archiaci* and the Givetian *Sp. anossofi* suggest an earlier Upper Devonian horizon (Frech & Arthaber 14).

From the Mashhad (Meshhed?) district farther southeast, more especially the hills near Raband, Reed (60 b) has described a fauna which includes the coral *Cyathophyllum* cf. *hexagonum* Gold., and the brachiopods *Spirifer verneuili* var. *persica* Reed, *Stropheodonta interstrialis* Phill., *Strophalosia?* sp., and *Rhynchonella* sp.

Afghanistan and the Western Himalayas. The Frasnian fauna has been obtained at a number of localities in eastern Afghanistan

and the western Himalayas. It is best known from Chitral in the Hindukush range, and the geological occurrence there has been discussed by Hayden (21), while the fossils themselves have been described by Reed (61). The Chitral region (lat. 35° 48′ N. long. 71° 46′ E.) comprises several localities, the two most important being Shugram and Koragh. The fauna consists chiefly of corals, bryozans, brachiopods and pelecypods. The corals include many Cyathophylloids, among them a variety of the characteristic European *C. torquatum* Schlüter (var. *orientalis*), *C. cylindricum* Schulz., *C.* (*Thamnophyllum*) *trigeminum* Quenst., *C.* (*T.*) *multizonatum* Reed (a new form), *C.* (*Phacellophyllum*) *cæspitosum* Goldf. and *C.* (*Hexagoniophyllum*) *sedgwicki* (E. & H.). Also a *Phyllipsastræa* (*P. monticola* Reed). The Aseptata are represented by *Pachypora* (*P. cristata* Blumenb., and a variety, and *P. polymorpha* Goldf.), and by varieties of typical European species of *Striatopora* (*S. devonica* Schlüter, and *S. angulosa* Gürich). A variety of *Alveolites suborbicularis* Lam. and species of *Plagiopora* and *Thecostegites* complete the list.

Among the brachiopods, the following may be especially noted as characteristic forms of the European Frasnian. *Craniella obsoleta*, *Stropheodonta dutertrii*, *Athyris pushiana*, and the *Spirifers*. Among the latter *S. verneuili*, *S. archiaci*, and *S. bifidus* are very characteristic, while the related *Cyrtiopsis murchisonianus* (de Koninck) is abundantly represented by numerous varieties. Other characteristic fossils are *Aviculopecten ingriæ* and *Spirorbis omphalodes*.

This fauna has many characters in common with that described by Tschernyschew from the western slopes of the Urals (Stage D_3) and by Perna from the eastern Urals. The fauna is however equally characteristic of western European Frasnian beds, especially of the Iberg limestone of the Harz.

There seems to be no reason for considering the existence of a direct connection with the Ural region, that indicated on the map (Fig. 114), across Persia, being ample to account for the presence of this fauna in central Asia, and in view of its wide distribution, in the Urals as well.

From a locality at the west foot of the Hajigak Kotal in Afghanistan, Hayden (21 & 22) has obtained a small Upper Devonian fauna of the same type. This comprises corals: *Cyathophyllum* cf. *hypocrateriforme* Goldf., and *Striatopora* sp. and the brachiopods *Spirifer archiaci* Murch. *Hypothyridina cuboides* (Sow.) (Fig. 112), *Camarotœchia* cf. *amaliusi* Goss., *Productella subaculeata* Murch. (Fig. 113), *Strophalosia productoides* Murch., and *Stropheodonta interstrialis* Phill.?

From three localities in the western Himalayas, Reed (60) has described Upper Devonian fossils of this type. These localities are Byans (lat. 30° 17′ N., long. 180° 50′ E.), Kanaur (Kanauar) lat. 32° N., long. 77° E.), and Upper Spiti (lat. 32° 10′ N., long. 78° E.), all close to the Chinese (Tibetan) border or even within it. The species are mostly brachiopods, including *Atrypa desquamata* (Sow.), *A. aspera* Schloth., *Pentamerus* cf. *sublinguifer* Maurer, *Camarophoria* cf. *phillipsi* Dav., *Wilsonia* cf. *omega* Whidb., *Orthis* aff. *bistriata* Tschern., *Orthotetes* aff. *crenistria* Phill., *O. umbraculum* Schloth.? (from Spiti), *Productella* or *Strophalosia* sp. Other fossils include *Pterinopecten* or *Aviculopecten* sp., *Orthoceras* sp., *Favosites* cf. *basaltica* Goldf., a Cyathophylloid, and *Idiostroma yulangensis* Reed.

Turkestan and the Tianshan range. Upper Devonian fossils of Frasnian age have been described from several localities in Turkestan, as for example from eastern Ferghana, where one section of the great series of Palæozoic limestones before mentioned, comprise gray limestones with Upper Devonian brachiopods. These include *Spirifer archiaci* Murch., *Dielasma sacculus* Mart., *Athyris concen-*

tricus v. Buch, etc. (Muschketow 51). Nalivkin (53a) also listed many Upper Devonian species from Ferghana, including several species found at Chitral. He also listed *Spirifer verneuili*, *S. archiaci*, *S. tenticulum*, and *Rhynchonella letiensis*, from the Pamirs.

Von Weber (74) has described Upper as well as Lower Devonian from Turkestan, the former with *Spirifer verneuili*. Previously Romanowsky (V, 26) has described Devonian fossils from Turkestan, including the characteristic Upper Devonian *Spirifers* (*S. archiaci*, *S. verneuili*, etc.), and other forms, several of them new.

From the neighborhood of Djitim-tau near the Djakbolot Pass, in the Middle Tianshan range, Valdasz (73) has described the following species of Upper Devonian fossils, collected by Dr. Gyula Prinz in 1906. *Spirifer verneuili* Murch., *Rhynchonella omaliusi* Goss., *R. boloniensis* d'Orb., *R. guillieri* Oehl. Finally from Gouchouc in western Tibet, Desmazures (8) has described a Frasnian fauna comprising *Hypothyridina cuboides*, *Pugnax pugnus?*, and *Atrypa reticularis*. These and the Tianshan deposits may be considered as representative of the Upper Devonian of the extreme west of Greater China.

Kirghiz Steppes. In the Kirghiz steppes of Siberia and in the Government of Tomsk and the southern part of the Government of Yeniseisk, Devonian rocks are widely distributed. In the Kirghiz Steppes, Upper Devonian rocks are strongly developed in the southern part of the Akmolinsk province, and within the boundaries of the districts of Akmolinsk and Pavlodar of the Semipalatinsk province. On the west the deposits are bordered by the river Ishim whence they spread in an easterly direction to the basins of the Chiderta and Ulenta, and reach the Irtysh as scattered insular areas.

The strata consist in the main of quartzites, metamorphic schists, and red and gray sandstones and conglomerates. The development of limestones is comparatively weak. The quartzites and

metamorphic schist may represent early Middle or possible Lower Devonian. Middle Devonian limestones also occur, and have already been noted. The Upper Devonian includes dark gray argillaceous, sometimes sandy, compact limestones, with the following brachiopods: *Productus subaculeatus* Murch., *P.* cf. *prælongus* Sow; *P.* cf. *dissimilis* de Kon., *Strophalosia productoides* Murch., *Chonetes nana* Vern., *Orthis interlineata* Sow., *Schizophoria striatula* Schl., *Spirifer verneuili* Murch., *S. archiaci* Murch., *S.* cf. *mesacostalis* Hall, *Athyris concentrica* v. Buch, *Cyrtiopsis murchisoniana* (de Kon.) and *Camarotœchia pleurodon* Phill. Limestones with *Goniatites* cf. *lifer* Sow., and *Prolecanites asiaticus* Karpinsky, also occur.

In the Government of Tomsk the Upper Devonian strata, exposed on the banks of the Tomi near Tomsk etc., are very similar to those of the Kirghiz Steppes. Most extensively developed, especially in the latter region are the red sandstones and conglomerates, which have a great thickness, and are evidently of continental origin. (For further details see Krasnopolsky 32, 33, and Bodgdanowitch 3).

Early Upper Devonian from the Pamirs.

On the left bank of the Ak Baital river, on the north side of the Pamir Plateau, there is exposed a dark gray compact limestone, underlain by carbonaceous shales with thin courses of limestone, and occasional bands of sandstone. Both limestone and sandstone courses are full of brachiopods, over a thickness of 60 to 70 feet. Underlying these beds are coarsely pisolitic limestones, with pisolites up to 15 mm. in diameter. They contain small *Rhynchonellidæ*, and are associated with hard compact limestone with silicified corals (Hayden 22). The fossils of the brachiopod-bearing beds form a remarkable assemblage (Reed 61), in which *Camarotœchia baitalensis* and its varieties predominate, forms having closely allied, if not identical representatives in Persia, Europe and America. Many other species

of American affinities are present in this assemblage, including *Productella arctostriata* Hall, *P. hirsuta* Hall, *P. lachrymosa* Hall var. *lima* Conr., and var. *stigmata* Hall, *Strophalosia truncata* Hall, and *S. muricata* Hall, while American species of *Camarotœchia*, *Camarophoria*, and *Ambocœlia* are represented by closely allied new species. One of the most abundant and characteristic species is *Spirifer pamiricus*, a type closely related to, and probably derived from, *S. anossofi* of the Middle Devonian of the northern region. Indeed the relationship of this fauna to that of the Boreal province is much closer, than it is to that of west Europe, many species found in the Urals being present, while the typical west European forms are absent. Corals also are practically absent, and the fauna is entirely distinct from that of the Frasnian beds of neighboring districts in Turkestan or Afghanistan. It must be regarded as an earlier fauna invading this region while the connection with the Boreal region was still open (See map Fig. 104 p. 160). It thus probably represents the passage from Middle to Upper Devonian.

The Wetwin Shales of Burma.

In the Northern Shan States of Burma, near the village of Wetwin (lat. 22° 6′, long. 96° 38′), occurs a series of fine-grained yellow and gray shales resembling hardened fullers earth. They are not found in contact with the Eifelian beds of the Padaukpin region, but La Touche suggests that they appear to pass beneath them, from the direction of the strike, though this may be due to disturbance by faulting. The fauna of these shales (Reed 59) has nothing in common with that of the Middle Devonian limestones of the region, consisting chiefly of brachiopods (*Lingula*, *Chonetes*, *Camarotœchia*) and pelecypods, with the genera *Nucula*, *Palæoneilo* and *Paracyclas* predominating, but also including species of *Ontaria?*, *Prœcardium? Prothyris*, *Phthonia* and *Janeira*. The gastropods are represented by

two species of *Bellerophon*. Cephalopods are absent, but the crustaceans are represented by a fragment of *Phætonides* related to an American Lower Devonian species, and by *Echinocaris asiatica* Reed, similar to an American Hamilton species. There are also some remains of fishes. Reed points out the presence in the fauna of many American elements, these being more marked here than in the Padaukpin fauna. Some of the American forms are allied to, or perhaps identical with, members of the American Naples fauna, though *Manticoceras intumescens* is absent. If this fauna is an early Upper Devonian fauna, representing the Boreal Intumescens fauna, it is difficult to determine its connection with the basins in which that fauna flourished, for it is unknown everywhere else on the Asiatic continent, where the early Upper Devonian faunas are of the Frasnian type. It may however be a local fauna, developed in early Upper Devonian time from survivors of the Mid-Devonian fauna in the extreme south-western part of the Chinese basin (see map, Fig. 109 p. 168) and the resemblance to the American fauna may be more apparent than real. The presence in these shales of *Echinocaris*, a form characteristic of brackish if not fresh (river) waters in Devonian time, as well as the presence of fish remains, animals still confined to the rivers in Devonian time, indicates that this was probably an estuarine region with unfavorable conditions of existence for marine faunas. This might still have been the case, if the fauna is found to be of early Middle Devonian age, the beds in which it occurs underlying the Padaukpin limestone; in that case it would represent a parallel to the American Marcellus fauna. (Grabau 18). At present this fauna must be considered one of the Devonian anomalies of the Asiatic continent.

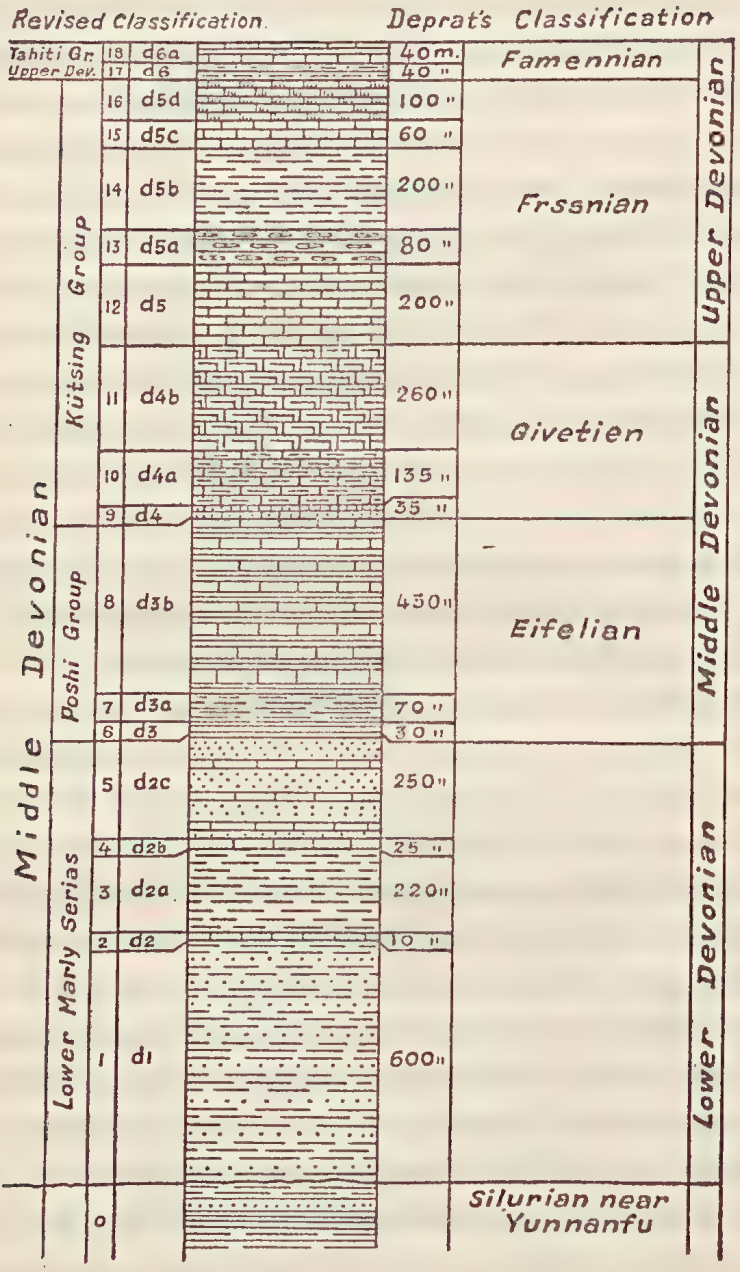

Fig. 118. Generalized Columnar section of the Devonian strata of eastern Yunnan. (Modified after Deprat). o. Silurian (Miaokaoshan) 1–16, Middle Devonian including probably the Tzuifengshan series in 1; 17–18, Upper Devonian (For details of formations see Fig. 119.)

The Devonian of China.

Devonian strata are well developed in China and their fossils are, as a rule, well preserved. Only Middle and Upper Devonian

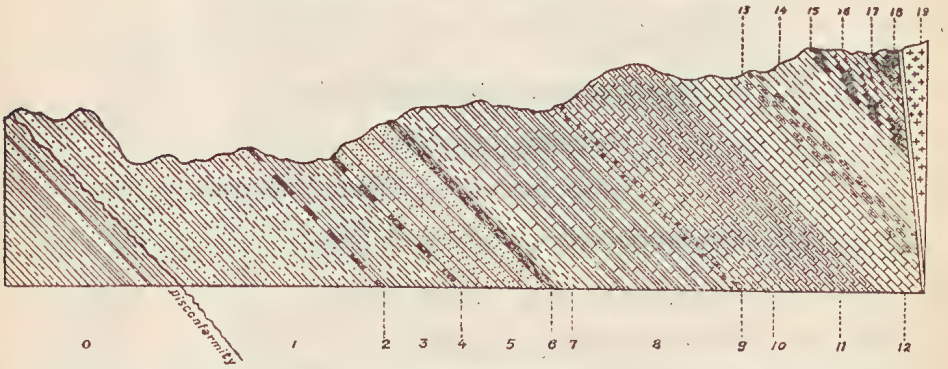

Fig. 119. Cross-section of the Devonian strata from the valley of the Tie-Tchen-ho to the limestone ridges of Ta-pin-pou, East Yunnan. (Modified after J. Deprat.). o. Silurian and older; 1-5 Lower Marly series of Middle Devonian, with perhaps some continental Lower Devonian; 1, marls and sandstones (continental) with *Entomis;* 2, limestone with *Spirifer* cf. *nudus;* 3, marl with *Athyrisina plicata*, etc; 4, limestone with *Spirifer* cf. *jouberti;* 5, sandstone with *Actinopteria deprati* and *Tentaculites.* 6-8, Poshi Group; 6, shaly limestone with corals; 7, shaly limestone with *Calceola;* 8, marly limestone with corals and brachiopods. 9-16, Kutsing group; 9, limestone with *Atrypa aspera;* 10, 11, limestone and marly limestones with *Stringocephalus burtini;* (9-11, Kuahsinshan beds); 12, limestone with *Hypothyridina procuboides;* 13, marls with *Strophalosia productoides;* 14, marls with *Reticularia undifera;* 15, rosy limestone; 16, white crinoidal limestone with *Reticularia maureri*, and *Pugnax pugnus.* 17, 18, Tahiti Group, Upper Devonian; 17, gray limestone with *Spirifer chinensis* var. *yunnanensis;* 18, marly limestone with *Spirifer tenticulum* var. *quadrangularis* and corals; 19, igneous rock faulted against sediments.

marine strata are known from China, the marine Lower Devonian being entirely absent, though represented by continental strata which carry a few plant remains (*Arthrostigma*). In the Kütsing region the lower part of the Upper Silurian Miaokaoshan group, with *Spirifer tingi, S. bourgeoisi* (erroneously referred to on p. 126 as occurring in the Lower Silurian Mientien group) and other fossils, passes upward into sandy beds with *Ceratiocaris*, *Leperditia*, and fish remains, the whole series having a thickness of some 400 meters. This is succeeded with apparent conformity by the shales and sandstones of the Tzuifengshan Series of red and gray sandstones and shales which also

contain fish-remains while the upper beds are characterized by *Arthrostigma gracile* Daws. This plant, according to Halle, indicates Lower Devonian age. These beds are followed by Middle Devonian strata. The subdivisions now recognized are as follows:

Subdivisions of the Devonian of China.

III Upper Devonian or Tsinglingian

6 *Hanchung formation*

5 *Tahiti formation* (East Yunnan)

II Middle Devonian or Yunnanian

C. Kütsing Group (Kütsingian)

4 *Tungshan limestone*

3 *Kuahsinshan beds.*

B. Poshi Group (Poshian)

2 *Huanglienpo beds* (S. Szechuan)

1 *Calceola beds of Poshi* (Probably equivalent of preceding)

A. Lowest sandy and marly Series (in part).

I Lower Devonian.—Tzuifengshan Group (Continental)

MIDDLE DEVONIAN OR YUNNANIAN.

(See Sections, Figs. 118-120)

The Lower Series. The sandy and marly series at the base of the section has been referred by Deprat and Mansuy to the Lower Devonian. This was done because of the presence in those beds, of a shell referred by Mansuy to *Sieberella sieberi* var. *rectifrons*, a characteristic Lower Devonian fossil of Europe, and one of *Spirifer fouberti*, a species also found in the Lower Devonian of France. The first of these forms is however so poorly preserved, being known only from a single crushed impression, that identification is extremely doubtful, while the second is only tentatively referred to the European

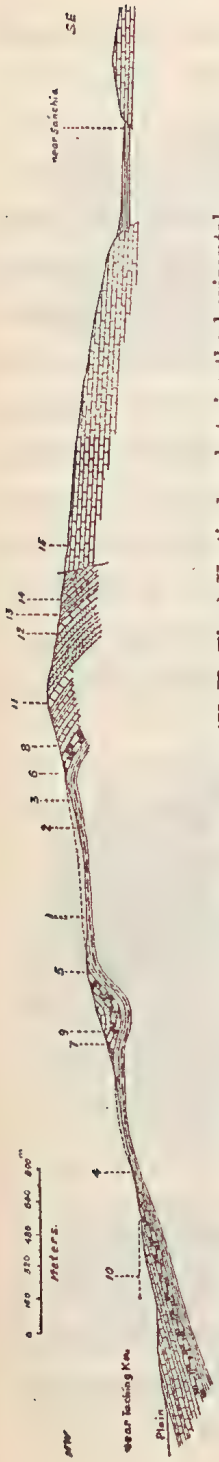

Fig. 120. Section of T'ung-Shan, near Kütsing, East Yunnan. (V. K. Ting) Vertical scale twice the horizontal.
The T'ungshan limestone and shale series (Middle Devonian) (beds 1-11) forms the northwestern part of the hill. It is disconformably succeeded by Dinantian sandstones, shales and limestones, which in turn are in fault contact with Upper Carboniferous limestone: 1-11, Localities which have furnished Middle Devonian fossils; 12-14, Localities which have furnished Dinantian fossils; 15 Locality for Upper Carboniferous fossils.

species, Mansuy himself considering the identification as doubtful. All the other species found in association with these two shells have Middle Devonian affinities. In view of the extent of the Lower Devonian, as previously outlined, we are warranted in relegating all except the basal division to the Middle rather than the Lower Devonian.

The Poshi Group. This is best developed in eastern Yunnan, where, at Poshi, it consists, according to Deprat, of calcareous shales and limestones abounding in corals, among which the characteristic form of the lower Middle Devonian of west Europe, the peculiar *Calceola sandalina* (Fig. 99) deserves special mention. Besides this form, there are many other corals, the genera *Cyathophyllum* (Fig. 121), *Cystiphyllum*, *Favosites* (Fig. 122) and *Alveolites*, being especially well represented. Essentially the same horizon has been observed by Loczy at Huang-lien-po (Hoaling-pu) in southern Szechuan, where it is represented by the Huanglienpo series, which consists of dark limestone, alternating with shales, and is of no great thickness. It rests disconformably upon pre-Devonian rocks (Silurian), and is covered by red sandstone of Mesozoic age.

Associated with the corals in this limestone are many brachiopods including *Camarophoria sutshuanensis* Loczy (Fig. 123), *Chonetes orientalis* (Fig. 124), *Gypidula loczyi* Grabau (Fig. 125), *Camarotœchia elliptica* var. *sinensis* Grabau (Fig. 126), *Cryptonella whidbornii* Davids. (Fig. 127), and species of *Spirifer* and other genera. A remarkable fact is, that none of these species of brachiopods have been found in the Kütsing area in eastern Yunnan, and this suggests that the horizon is lower than anything there found.

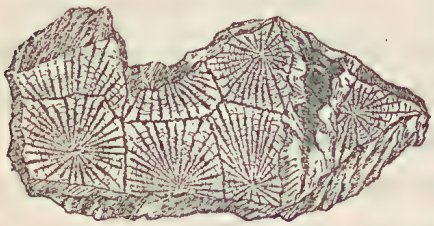

Fig. 121a, *Cyathophyllum loczyi* Frech. Section. Middle Devonian Szechuan.

What is probably the same horizon, was found by Loczy in the gorge of the Pei-Shui-Kiang (Paj-sui-king) in southern Kansu. Here the fossil-bearing beds, are bituminous, dolomitic and marly limestones, which rest upon limonitic quartz-sandstone, with intercalated shales. The age of this sandstone is unknown but may be Silurian. This early Middle Devonian horizon with corals, also occurs in some sections in north Szechuan, these northern occurrences marking the first transgression of the Middle Devonian sea from the south into the Tsingling geosyncline. The occurrence of this early Middle Devonian fauna in the Padaukpin beds of the Northern Shan States of Burma, shows that the path by which these faunas entered China has been along the Himalayan geosycline, to the south of the Tibetan land mass. (See the Palæogeographic map, Fig. 101. p. 156).

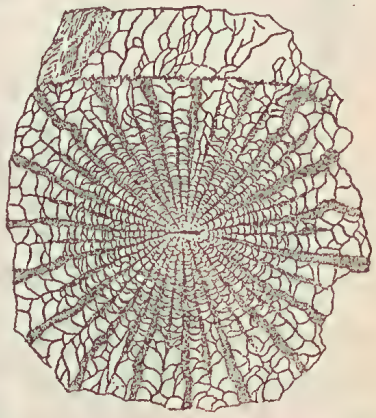

Fig. 121b, *Cyathophyllum loczyi* Frech. A corallite enlarged.

It is probable that beds belonging to this lower division of the Middle Devonian occur in the Kütsing region in eastern Yunnan, but they have not been identified. Middle Devonian beds rest disconformably upon the Upper Silurian (*Miaokaoshan limestone*) or on continental Lower Devonian (*Tzvifengshan beds*), thus indicating an eastward transgression of the sea, and overlap over the older beds of the more westerly region.

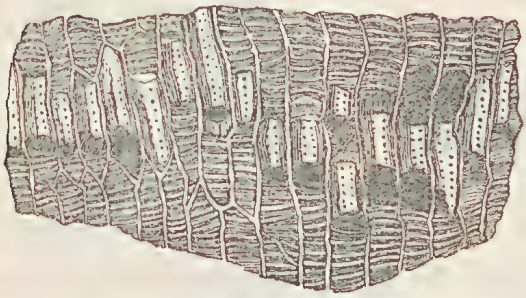

Fig. 122. *Favosites goldfussi* Middle Devonian. Szechuan.

The Kütsing Group. This is well developed throughout eastern Yunnan, and probably extends to eastern Kwangsi and southern Hunan.

Fig. 123. *Camarophoria sutshuanensis* Loczy. Middle Devonian, Szechuan.

The lower beds are limestones and shales, and carry small species of Orthis (*Rhipidomella kützingense* Grabau), and *Athyris vittata* Hall, and varieties (Fig. 128), and apparently also *Athyrisina plicata* (Mansuy) and varieties, and the remarkable Chinese species *Yunnanella synplicata* Grabau, allied to *Y. hanburii* (Fig. 137). The transgression appears to have extended eastward to the Nanning region of southern Kwangsi, where

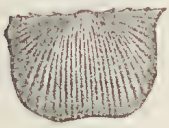

Fig. 124. *Chonetes orientalis* Loczy. Middle Devonian Szechuan. ×1½.

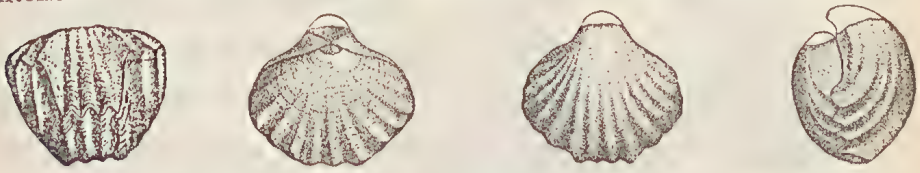

Fig. 125. *Gypidula loczyi* Grabau. Middle Devonian, Szechuan; ×1½.

beds with a similar fauna rest upon the Miaokaoshan limestone with

Spirifer tingi. (Upper Silurian or Monroan).

In the Lu-Chuan-Hsien district north of Yunnan-fu, the lower portion forms the *Kuahsinshan beds*, which are especially characterized by *Stringocephalus burtini* (Fig. 103, p. 159), the fossil most characteristic of the upper Middle Devonian (Givetian) of western Europe, and which is known from other regions in Asia, and from western North America as well. A more robust species *Stringocephalus obesus* Grabau (Fig. 129) occurs in the *Tungshan limestone.* The most widespread species of the Kuahsinshan beds is the small smooth Spiriferoid *Emanuella takwanensis* (Kayser) (Fig. 130), while the Tungshan limestone is especially characterized by species of *Meristella*, (Fig. 131) and by *Schizophoria* (3 species) (Fig. 132), and *Atrypa auriculata* Hayasaka. (Mansuy V, 10; Yabe and Hayasaka, IV, 39; Grabau 19). From beds of this, or a lower horizon, Frech obtained a specimen of *Gypidula calceola* (Frech) (Fig. 133), the characters of which suggest *Sieberella sieberi* of the Lower Devonian.

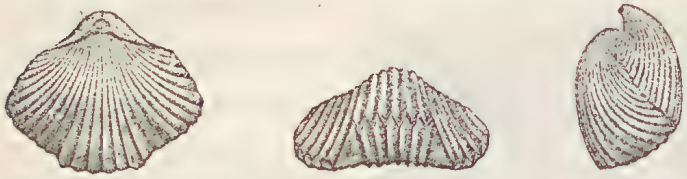

Fig. 126. *Camarotœchia elliptica* var. *sinensis* Grabau; Middle Devonian, Szechuan.

Fig. 127. *Cryptonella whidbornii* Davids. Middle Devonian, Szechuan etc. ×2.

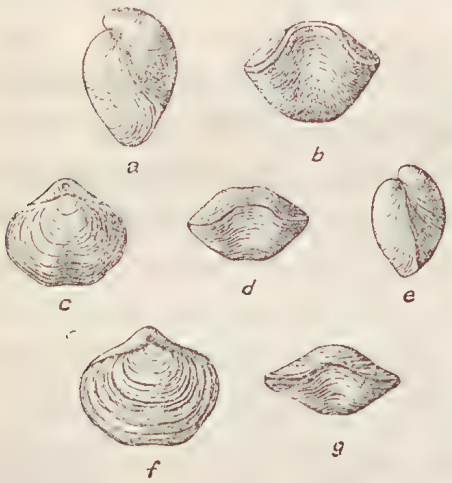

Fig. 128. *Athyris vittata* Hall: *a–b*, typical form; *c–e*, var. *antecedens* Grabau; *f–g*, var. *intermedia* Grabau; Middle Devonian, Yunnan etc.

UPPER DEVONIAN OR TSINGLINGIAN.

Tahiti Formation. Beds of Upper Devonian age are more wide-spread than those of Middle Devonian age. In eastern Yunnan

Fig. 129. *Stringocephalus obesus* Grabau. Middle Devonian, Yunnan.

(Tahiti region) they are represented by the *Tahiti limestone*, which is characterized by corals and brachiopods, many of the latter still having Middle Devonian affinities. The most distinctive of the brachiopods are: various species of *Camarotoechia* and *Atrypa*, *Pugnax pugnus* (Martin) (Fig. 134), *Spirifer chinensis* var. *yunnanensis* (Mans.), and *Spirifer triplisinosus* Grabau.

Fig. 130. *Emanuella taiwanensis* (Kayser); Middle Devonian Yunnan, etc. ×1½.

These beds are absent in the Kütsing region, farther east in Yunnan, having either never been deposited or, what is more likely, having been eroded before deposition of the Carboniferous beds.

Hanchung Formation. The highest Devonian strata are represented by the *Hanchung beds*. These are typi-

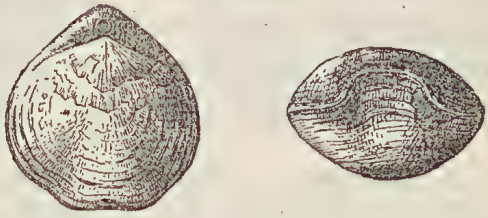

Fig. 131. *Meristella kütsingensis* Grabau. Middle Devonian, Yunnan.

cally exposed in a number of localities in the Hanchung district of southern Shensi, and in the adjoining district of southern Kansu and northern Szechuan. They are indeed most typical throughout the Tsingling geosyncline, resting so far as known, disconformably upon the Lower Silurian (Niagaran). They are

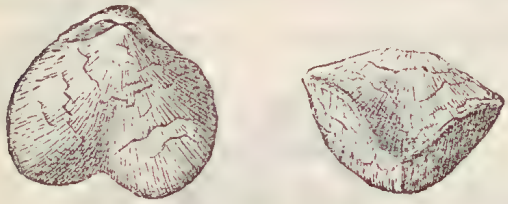

Fig. 132. *Schizophoria excellens* Grabau. Middle Devonian, Yunnan.

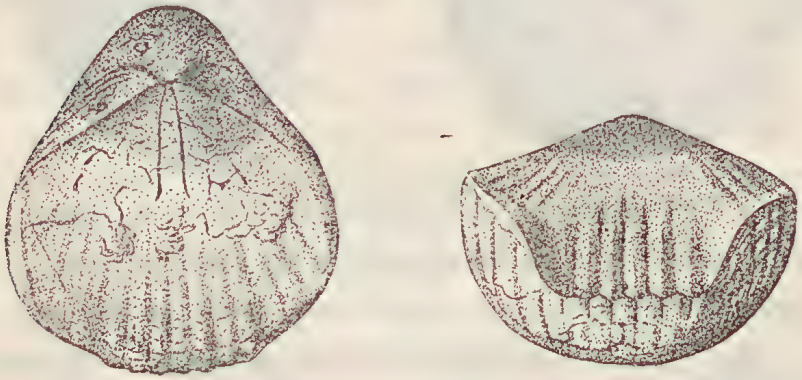

Fig. 133. *Gypidula calceola* (Frech); Middle Devonian, Yunnan.

characterized by the very variable *Spirifer chinensis*, (Fig. 110) a modification of the *Spirifer verneuili* type of Europe, which in China has developed a large number of distinct mutations.* *Spirifer wangleighi* Grabau is another characteristic and striking fossil. With these are associated four species of the genus *Cyrtiopsis* Grabau (*C. davidsoni* Gr. (Fig.

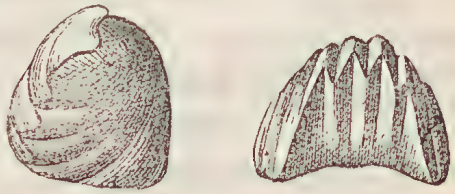

Fig. 134. *Pugnax pugnus* (Mart.); Upper Devonian., Yunnan, etc.

*For description of these and the other Devonian brachiopods of China, see Palæontologia Sinica, series B, Vol. I, fascicle 2. 1924. These brachiopods are sold in Chinese drug stores under the name Shih-yen (石燕) or "Stone Swallows," and they are regarded as possessing medicinal qualities.

135), *C. shansiensis* Gr., *C. graciosa* Gr. (Fig. 136), and *C. transversa* Gr. This genus, is also represented in western Europe by *Cyrtiopsis murchisoniana* (de Kon.). Other characteristic forms of these beds are *Yunnanella hanburii* (Davids.) (Fig. 137), and *Productella subaculeata* Murch. (Fig. 113, p. 170), besides species of *Shizophoria*, (Fig. 138), *Hypothyridina* (Figs. 139, 140), *Atrypa* (Fig. 141), etc.

Fig. 135. *Cyrtiopsis davidsoni* Grabau, Upper Devonian, central and south China.

Fig. 136. *Cyrtiopsis graciosa* Grabau. Upper Devonian. China.

The *Hanchung formation* is traceable southeastward into the border region of Hunan, Kwangtung and Kwangsi, where, in an area covering the adjoining portions of these three provinces, it is always readily recognized by the distinctive character of its fossils. So far as known, this formation rests, in this more southern region, with a disconformity upon Middle Devonian or older strata.

Fig. 137. *Yunnanella hanburii* (Davidson). Upper Devonian, central and south China.

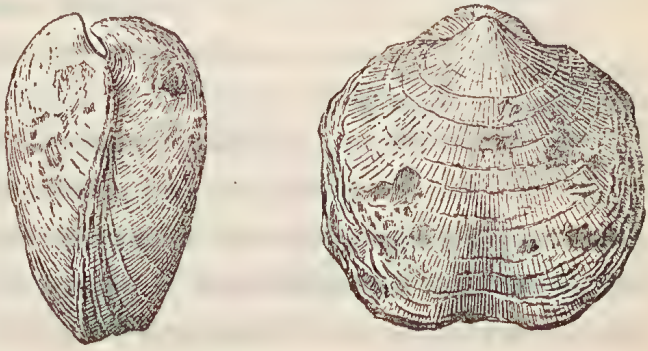

Fig. 138. *Schizophoria striatula*. Upper Devonian, Kansu.

It is a remarkable fact, that this fauna did not extend westward to any great extend, for no undoubted representation of it has been found west of the Kweichow basin, in Yunnan and

southern Szechuan. It seems probable that this fauna entered the Chinese province to the north of the Tibetan island of the period (see map Fig. 109, p. 168) along the geosyncline now represented by the Kwenlun and Nanshan systems of ranges.

Once having entered the basin, it quickly became modified into a large number of local mutations, so that the Upper Devonian fauna of China, even more than the Middle Devonian, bears the stamp of a local or provincial fauna.

The Devonian is wholly absent from northeastern and eastern China but it extends for a short distance south into Indo-China.

Fig. 139. *Hypothyridina procuboides* (Kayser). Upper Devonian, Central and South China.

Devonian of Indo-China.

Devonian fossils have been described by Mansuy from Tonking, Annam and Laos, but the stratigraphic relations of these fossil-bearing beds is still very obscure, the earlier work of Deprat being subject to revision. Where recent work has been carried on in detail, Middle Devonian strata with *Spirifer speciosus* (Fig. 100, p. 156), originally referred to the Silurian, rest disconformably upon Ordovician or older beds.

A certain number of fossils has been described by Mansuy as related to, or identical with, species elsewhere known from the Lower Devonian. Thus from Pien-doc, in the That-Khé quadrangle of eastern Tonking, he obtained from shales *Chonetes zuleri* Mans., related to *C. verneuili* Barr. of the Konjepruss limestone, and *Hipparionyx lantenoisi* suggestive of *H. proximus* of the American Oriskany. Neither of these forms is well preserved, judging by the illustrations, and precise comparison with

the Konjepruss *Chonetes* is scarcely possible, while the *Hipparionyx*, has only a distant similarily to the American form, in the flatness of one valve and the curving muscular ridges. The material is entirely insufficient to permit reference to a Lower Devonian horizon, especially in the face of the known facts regarding the distribution of the beds of this division. Other species from other localities regarded by Mansuy as related to Lower Devonian species, are equally indefinite and are, moreover, associated with forms referred to a Middle Devonian horizon.

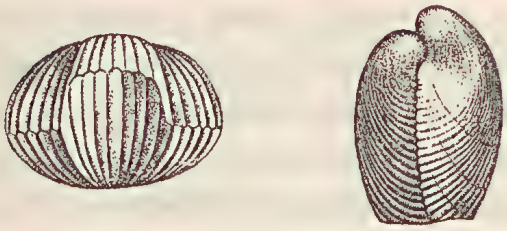

Fig. 140. *Hypothyridina parallelepipeda* Bronn Upper Devonian, central China.

The most wide-spread Devonian horizon of Indo-China is the lower Middle Devonian or Eifelian with *Calceola sandalina* (Fig. 99, p. 154) and *Spirifer speciosus* (Fig. 100, p. 155), as the leading fossils. The latter was originally described as *Spirifer tonkinensis* by Mansuy and referred to the Silurian, but Frech recognized its affinity with the European *S. speciosus* of the Eifel beds, a correction subsequently adopted by Mansuy. The original *S. tonkinensis* may be regarded as a variety of *S. speciosus*.

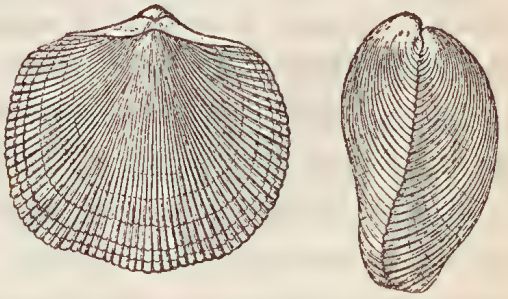

Fig. 141. *Atrypa desquamata*, Sow. Upper Devonian, central and south China.

These Eifelian beds are best developed in the north-eastern part of Tonking (Yên-minh, Cao-bang, Ha-long, Pho-binh-gia, and That-khé quadrangles). Among other characteristic European species present in these beds are—*Cambophyllum brancai* Frech, *Spirifer aperturatus* Schlotheim, *S. undiferus* Roemer, *Atrypa reticularis* Linné,

A. aspera (Dalman), and others, besides many new species related to European forms.

Beds of Givetian age appear also to be present in Tonking though less well characterized. From south-western Tonking (Vanyên quadrangle) however, a fauna has been obtained which is remarkable, in that it carries pelecypods very closely related to, if not actually identical with species found in the Hamilton and Chemung beds of New York. Species thus identified by Mansuy are *Mytilarca* (*Plethomytilus*) *oviformis* Hall, *M. muongthensis* Mans, *Schizodus chemungensis* Hall, *Pteronites profundus* Hall, and *Goniophora spatulata* Mans., related to *G. hamiltonensis* Hall. It must be confessed, that although these specimens are all more or less crushed, the resemblance to the American forms is so close as to be startling. The occurrence of these forms in America is such as to suggest that they formed elements of the Atlantic fauna, and it is certainly a most remarkable case of long migration with slight or no modifications, which these forms present, for they must have migrated entirely across Europe and southern Asia, entering the Chinese basin through the Himalayan geosyncline. So far, no records of their occurrence along the route of migration appear to be known, but that these forms must occur elsewhere in Asia and in Europe, is certain, unless their remarkable similarity to the American forms is due to parallelism in development.

No undoubted Upper Devonian has yet been discovered in Indo-China.

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CHAPTER VII.

THE DINANTIAN OR MISSISSIPPIAN SYSTEM.

General Geographic Relationships.

The great limestone series which in Britain lies between the Coal-measure beds and the Old Red Sandstone (Devonian), has long been known by the name of Carboniferous Limestone a name still employed in much of the literature. In some sections it was also designated "Mountain Limestone" because from its superior resistance to erosion it produced mountainous topography. It will be remembered that von Richthofen, during his travels in China, identified the great limestone series of north China, now known to be of Ordovician age, with the Carboniferous limestone (Kohlenkalk) or Mountain limestone (Bergkalk) of Europe, believing it to be continuous with the coal-bearing series which overlies it. The Carboniferous Limestone is by far the most prominent Palæozoic limestone of west Europe where it is rich in organic remains. In England, where it sometimes attains a thickness of 4,000 feet or more, it generally rests disconformably or unconformably upon the older rocks, showing a transgressive relation, the successive beds overlapping north-westward against the old land of Atlantica; but in Belgium, where the thickness reaches 760 meters, the succession appears to be complete, the lowest members of the Dinantian resting upon the uppermost Devonian beds. It is from Dinant, on the Meuse river in Belgium, that the name Dinantian is derived, while the name Mississippian was given to the American formations of corresponding age, because of the fine exposures of these strata in the valley of the Mississippi River. Formerly these formations were called *Subcarboniferous*, and they are still frequently classed as Lower Carboniferous (Carbonifère Inférieur, Unter-Karbon). Both the European and the American designations are serviceable, since the seas in which the respective formations were

deposited, were essentially distinct, and for the most part had very little inter-communication, as may be briefly set forth.

General Characters and Development.

At the opening of Mississippian time, the interior sea of North America had reached its maximum contraction; the outlet to the Atlantic was probably closed, though this is not entirely certain. Nevertheless, the greater part of the Appalachian geosyncline was above sea-level, and into it great alluvial fans of sands and pebbles (Pocono conglomerates) were being built outward from the old land. Along the eastern margin of the interior sea extensive sand deposits, enclosing shallow-water organisms, were formed (Waverley group), while farther in the interior of the central sea, more calcareous sediments were forming. In this early epoch, the interior sea was very diversified and hence there were many local faunules which replaced one another or occupied a more or less overlapping relationship. In the more open western waters however, the Cordilleran geosyncline, the deposits and faunas were more uniform, resulting in the formation of the great Madison limestone of western North America. The faunas of this limestone, together with those of some of the formations in the interior, show many affinities with the Devonian faunas which preceded them and from which they were in the main derived. The chief center of modification, as usual at this time, appears to have been the circumscribed Boreal sea. There was, however, one faunal element of the American Mississippian that appears to have been wholly indigenous to the interior Mississippian sea; that was the wonderful crinoid fauna which has made the Burlington and Keokuk beds of North America famous throughout the world. Nowhere else is known such an abundance* and such wealth of variety of these organisms,

* More than 400 species are known from these rocks.

nor do they seem to have had many survivors after the period of their riotous efflorescence. The genera are however, for the most part also present in the Tournaisian of western Europe.

The southern border of the interior Mississippian sea of North America was still a low flat country, with sluggish rivers, as in Devonian time. Large areas of the low flat lands were covered by a residual deposit of deep black soil comparable to the modern black earth or "Tschernosem" of Russia (Grabau 11, p. 459). Over this flat country the sea transgressed slowly, entering first the estuaries and lower courses of the rivers and then spreading over the intervening lands. During this advance of the sea the black mud was in part reworked and incorporated as a basal bed in the series of deposits, or washed out to sea to form interbedded layers of black shale (Sunbury). In many sections it remained however, practically undisturbed, the successive deposits of the Mississippian sea overlapping one another against this basal black mud series. Thus this black mud, which today is a deep black bituminous shale (Chattanooga shale) occupies a rising position at the base of the overlapping Mississippian series. Its similarity to, and frequent downward continuity with the Devonian black shales has sometimes led to a confusion of the two.*

It is held by some students of these formations that the interior sea had a southward connection with the Gulf of Mexico, and that certain of the faunal elements entered from this direction. The uniform low flat character of the coast, however, with its black mud covering, and the progressive overlap of the successive formations southward against this black mud, speak against such an assumption. True, there is an area in the Mississippi Valley, where the older formations are covered by Tertiary strata, and where such a pathway

* It should be noted however, that this shale has also been thought to have been formed in deep stagnant water.

might have been situated. But the uniform character of the strata, and their overlaps on both sides of this area, suggest that they continue in a similar manner under the covered portions.

More debatable is the question of the opening of the Appalachian trough to the Atlantic in early Mississippian time. This was certainly the most direct route of communication between western Europe and central North America. That some inter-communication took place, is shown by many elements of similarity between the Tournaisian fauna of western Europe and the early Mississippian (Waverlyan) of North America. This is seen in the correspondence of crinoid genera, to a certain extent in the brachiopods, and especially in the cephalopods, certain genera of Goniatites (*Aganides*, *Muensteroceras*, *Prolecanites*, *Pericyclus*, etc.) being typical of the early Mississippian of central North America, and the early Dinantian of western Europe. On the other hand, the specific distinctness of these forms would favor a round-about, rather than a direct pathway of migration, or migration in both directions from an intermediate center. Furthermore, the only known marine deposit of early Mississippian age in the north-eastern end of the Appalachian trough, that at Windsor, Nova Scotia, has a fauna so entirely distinct from either the American Lower Mississippian, or the European Lower Dinantian, that it must be regarded as belonging to another province. The only province available for it is the Atlantic which, in that case, could not have been the home of the normal Lower Dinantian fauna.

From considerations of this kind we are led to abandon the idea of direct communication between Europe and America across the Atlantic in early Mississippian-Dinantian time, and turn to the Boreal sea (Fig. 142) as the probable home of the goniatite element. Migration northward through the Cordilleran channel, to the Boreal sea and onward through the Ural trough to west Europe was possible

for types which originated in America, while migration in a reverse direction was equally permitted to types which originated in Europe, or species originating in the Boreal sea may have migrated in both directions. It will be recalled that the evidence pointed strongly to the Boreal sea as the center of distribution of the goniatites in Devonian time. If we are correct in this supposition, it follows that

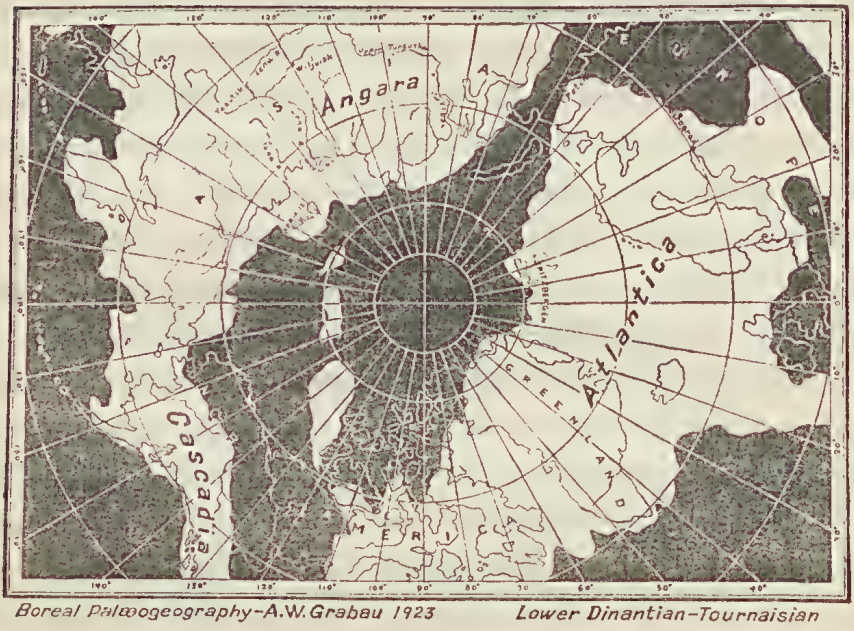

Fig. 142 Palæogeographic map of the Artic region showing the distribution of land and seas (black) in Tournaisian time.

the Boreal sea is the most logical center of distribution of these organisms in Carboniferous time, for these later goniatites, although they have split into a number of distinct branches each of which developed independently, all have their ancestry in the Devonian period. Indeed it seems not impossible, that goniatites developed in the first place in the Boreal sea, whence successive waves of emigration were sent out, into European and American, and more rarely, into Asiatic waters. Goniatites arose in the late Silurian or early Devonian

from nautiloid ancestors,* and the Boreal waters, subject as they were to repeated separation, with the accompanying uninterrupted periods of faunal isolation, formed an ideal center of such evolution. Until unmistakable evidence then points to another center, or centers, in which the goniatites arose and became differentiated, we shall consider that the Boreal realm was their ancestral home.

The European Dinantian has been divided into the following members, the lowest of which, the Etroeungtian, is of very limited distribution and represents the transition from Upper Devonian into the Dinantian.

SUBDIVISION OF THE EUROPEAN DINANTIAN.

III. VISÉEN. Limestones with *Productus giganteus, P. pustulosus, P. corrugatus, P. semireticulatus*, var. *concinnus, Chonetes papilionaceus, Lithostrotion junceum, L. irregulare, Syringopora ramulosa*, etc., *Goniatites striatus, G. sphæricus, G. obtusus, Glyphioceras mutabile, G. complicatum, Prolecanites serpentinus, Pronerites cyclolobus*, etc.

II. TOURNAISIAN. Limestones with *Spiriferina peracuta, S. octoplicata, Spirifer tornacensis, Rhynchonella acuticosta, Rhipidomella michelini, Porcellia puzo, Brachymetopus duponti, Archæocidaris nereis, Aganides rotatorius, Pericyclus princeps, Muensteroceras complanatum, Prolecanites clymeniæformis, Michelinia favosa, Lithostrotion basaltiforme, Bellerophon sublævis, Vestinautilus koninckı* etc.

I. ETROEUNGTIAN. Limestones with *Spirifer tornacensis, S. distans, Athyris royssi, Orthothetes crenistria, Productus scabriculus* and many Devonian forms (*Spirifer verneuili, Athyris concentrica, Schizophoria striatula, Phacops latifrons*, etc.).

* The author regards *Bactrites* as a separate parallel development of goniatitic characters in a derivative of orthoceran stock, and not as ancestral to the goniatites.

The detailed subdivision of the Dinantian or Carboniferous Limestone of England is as follows:

II. Upper Carboniferous (Pendleside).

A. *Posidonomya becheri* zone.

2. Sub-zone of *Glyphioceras spirale*.

1. Sub-zone of *Productus striatus*, *Nomismoceras rotiforme*.

I. Lower Carboniferous (Avonian).

B. Viséen (Kidwellian).

2. *Dibunophyllum* zone.

c. Subzone of *Cyathaxonia rushiana*.

(2) Beds with *Michelinia tenuisepta*.

(1) Beds with *Zaphrentis* aff. *enniskilleni*.

b. Sub-zone of *Lonsdaleia floriformis*.

a. Sub-zone of *Dibunophyllum* e.

1. *Seminula* zone.

b. Sub-zone of *Productus cora*.

a. Sub-zone of *Productus semireticulatus*.

A. Tournaisian (Clevedonian).

4. *Syringothyris* zone.

3. *Zaphrentis* zone.

b. Sub-zone of *Schizophoria resupinata*.

a. Sub-zone of *Spirifer* aff. *clathratus*.

2. *Cleistophora* zone.

b. Sub-zone of *Spiriferina octoplicata*.

a. Sub-zone of *Productus bassus*.

1. *Modiola* zone.

Where the marine Dinantian beds carry intercalations of terrestrial sediments or are more or less replaced by these, plants are common, among which the following genera are most typical.

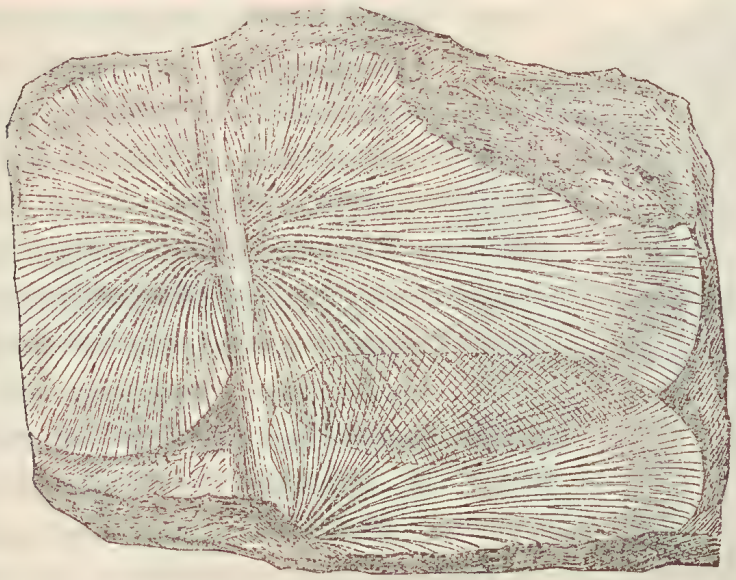

Fig. 143. *Cardiopteris frondosa* Schimp.

Sphenopteris (*S. schimperi*), *Archæopteris*, *Adianites*, *Rhacopteris*, *Cardiopteris* (*C. frondosa*) (Fig. 143), and *Rhodea* (Fig. 144). Also *Asterocalamites scrobiculatus* (Fig. 145), *Lepidodendron volkmannianum*, *L. veltheimianum* (Fig. 146), and internal impressions of this form, also called *Knorria imbricata* (Fig. 147).

Fig. 144. *Rhodea patentissima* (Ett.)

The Viséen is succeeded by the NAMURIAN which begins with beds carrying *Productus griffithanus*, *P. punctatus*, *P. scabriculus*, and sponge spicules, and is followed by the AMPELITES OF CHOKIER. In calcareous nodules in this formation, goniatites abound,

(*Glyphioceras beyrichianum*, *G. striatulum*, *Dimorphoceras atratum* etc.) and shells of *Mytilus* (*M. ampeliticola*, *M. carbonaria*), etc. The Namurian closes with the ARDENNES SANDSTONE, which contains *Productus carbonarius*.

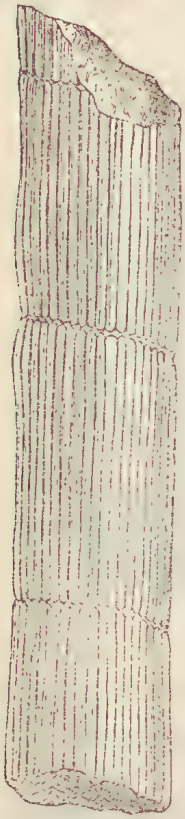

Fig. 145a.
Asterocalamites scrobiculatus Schl. Internal cast of stem.

The Namurian is followed by the productive coal series, which attains a thickness of nearly 3,000 meters. The lower division of this series carries anthracite, and its flora has still many Dinantian affinities (*Lepidodendron veltheimianum*, etc.), but this is replaced by the typical Westphalian flora in the higher beds.

In the lower coal-series are found marine intercalations, and these have yielded a typical late Dinantian fauna, including the goniatites *Glyphioceras reticulatum* and *G. beyrichianum* var. *tenuistriatum;* the brachiopods *Spirifer bisulcatus*, *Productus semireticulatus*, *P. carbonarius*, *P. longispinus*, *Rhipidomella michelini*, *Othotetes crenistria*, *Athyris royssi*, and *Lingula mytiloides*, and many pelecypods (*Aviculopecten*, *Pterinopecten*, *Solenomya*, *Parallelodon*, *Nuculana* etc.).

This fauna agrees in many respects rather closely with that of the Taiyuan series of north China, which will be discussed later, that division holding essentially the same position with reference to the typical Viséen.

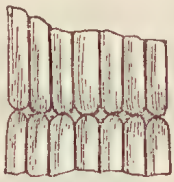

Fig. 145b.
Asterocalamites scrobiculatus Schl. Portion enlarged. (Longitudinal grooves do not alternate on opposite sides of joints as in *Calamites*).

This persistence of the Dinantian marine fauna raises the question whether the beds carrying it should not be classed as a

higher division of the Lower Carboniferous (Dinantian), in spite of the presence of typical Middle Carboniferous (Westphalian) species of plants. As we shall see later, the corresponding Taiyuan series of China represents a continuance of the transgressive movement which characterized the Viséen. If we consider that the west European Dinantian, exclusive of the beds in question, has a maximum thickness of less than 1,500 meters, while the equivalent beds of the Donetz basin of Russia, also largely represented by limestones, have a thickness of about 7,000 meters or nearly five times that of the west European beds, we may well doubt if the series in the latter region is complete. If not, it is quite possible that the Namurian and a part of the succeeding Lower Coal Series represent deposits formed during late Dinantian time, when in certain sections of the land the flora had already assumed the Mid-Carboniferous aspect.

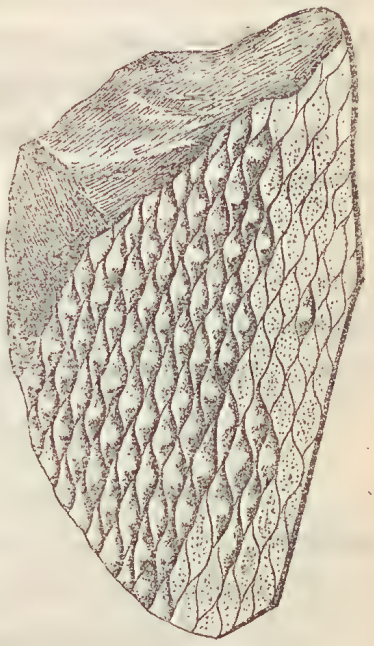

Fig. 146.
Lepidodendron veltheimianum (Sternb.) Impression of exterior.

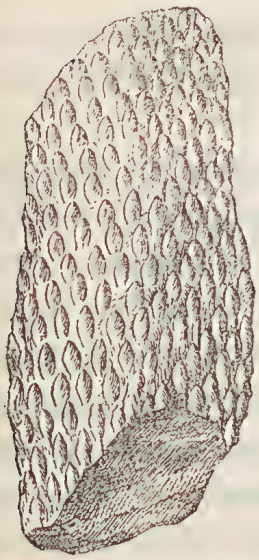

Fig. 147.
Lepidodendron veltheimianum (Sternb.). Internal cast (*Knorria imbricata*).

On the other hand we may assume the persistence of the Dinantian fauna into Mid-Carboniferous or Moscovian time, both in the west and the east, while in the Russian basin it became modified into the Moscovian

fauna. The fact, that *Spirifer bisulcatus* and *Schizophoria resupinata* occur together with species characteristic of the Ardennes sandstone (Namurian), in marine intercalation in the Upper Coal Series of west Europe (Mons basin), might argue for faunal persistence in that region, but does not prove it. It is a question of the relative value of marine faunas and land floras as indicators of a geological horizon.

In the valley of the Donetz river in southern Russia, the Lower Carboniferous or Dinantian (here often called Donjetian), is developed to a remarkable extent, ranging in thickness up to 7,000 meters. It consists of the following succession in descending order.

Table of the Dinantian of the Donetz Basin.

SUPER-FORMATION: MOSCOVIAN SANDSTONES, followed by limestone.

DINANTIAN:

7.—Shale, sandstone, and oölitic limestone with *Productus latissimus, P. elegans, P. longispinus, Schizophoria resupinata.*

6.—Two beds of marine limestone separated by shale and sandstone with *Productus latissimus, P. punctatus, Chonetes* cf. *variolarius*, and plant remains. The limestones contain: *Leptæna sinuata* de Kon., *Productus longispinus* Sow., *P. medusa* de Kon., *Retzia multiplicata* de Kon., *Spiriferina octoplicata* Sow., *Sp. insculpta* Phill., *Pugnax pugnus* (Mart.), *Camarotœchia acuminata* (Mart.), *C. reflexa* de Kon., *Camarophoria globulina* Phill., *Orthotetes resupinata* (Mart.), *Dielasma sacculus* (Mart.), *Spirifer trigonalis* (Mart.), *Phillipsia derbyensis* (Mart.).

5.—Coarse- and fine-grained micaceous sandstone, *with thin seams of coal*, and limestone with *Productus latissimus* Sow., etc.

4.—Gray limestone with *Prod. giganteus* Mart., *P. elegans* McCoy, *P. nysti* de Kon., *Fugnax pugnus* Mart., *Rhyn. pleurodon* Phill., *Chonetes papilionaceus* Phill., *Camarophoria rhomboides* Phill., *Spirifer ovalis* Phill., *S. trisulcosus* Phill.

3.—Gray chalk-marl with *Prod. giganteus* (Mart.), *Chonetes hardrensis* Phill., *Ch. papilionaceus* Phill., *Ch. dalmani* de Kon., *Orthotetes arachnoides* etc., bed of porphyry.

2.—Massive gray and black limestone with *Prod. corrugatus* McCoy, *P. semireticulatus* Mart., *P. pyxidiformis* de Kon., *P. pustulosus* Phill., *P. undifer* de Kon., *Spirifer cinctus* de Kon., *Euomphalus pentangulatus*, *Davisiella comoides* (Sow.), *Orthot. arachnoides* (Phill.), *Chonetes papilionaceus* Phill.

1.—Gray dolomitic limestone with finely plicated *Spirifers* of large size.

Subformation: Marine Devonian limestone.

Further north, near Moscow, the clastic sediments become more dominant in the Lower Dinantian, and beds of coal are quite common; marine fossils nevertheless occur. The upper Dinantian also begins with a coal bed, but is mostly marine with *Productus giganteus* and *Chonetes papilionaceus* and with *Fusulinella struvei* and other Foraminifera. It is followed by the marine Moscovian. Towards the north-west, the Dinantian is overlapped by the Moscovian, but in the Urals it is developed in marine facies, this forming

the pathway of connection with the Boreal sea. The Lower and Upper Dinantian are often separated by sandstones and shales with *Stigmaria* and *Nœggerathia*.

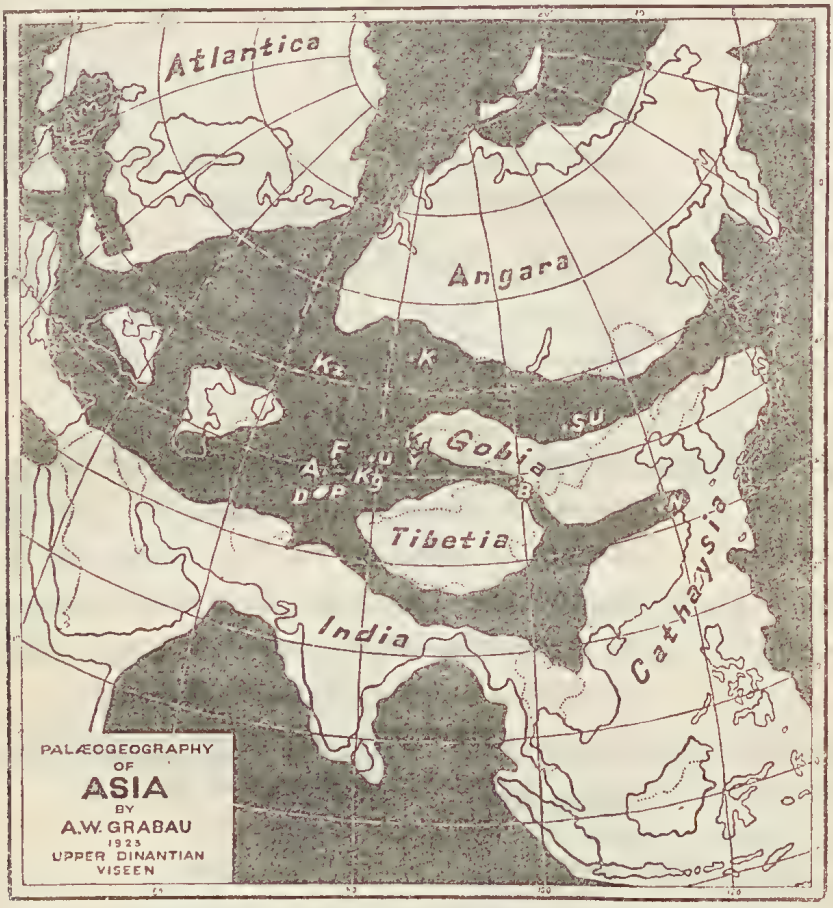

Fig. 148. Palæogeographic map of Asia, showing the distribution of land and seas (black) in Viséen time. A—Alai Tagh; B—Bardoun; D—Darwas mountains, an island in Viséen time; F—Ferghana; K—Kusnezk basin; Kd—Kuldja; Kg—Kashgar; Kz—Kirghiz Steppes; N—Nanking Hills; P—Pamir plateau; SU—Sair-Usu; U—Uch Turfan; Y—Little Yulduz Valley.

With the opening of the Viséen epoch, a great transgressive movement was inaugurated, this affecting various sections of Europe. Thus in a number of localities the Viséen is found to rest directly upon older rocks, being sometimes underlain by a basal conglomerate

or by plant-bearing beds which have been regarded as representing the Tournaisian. This is seen in Brittany, in Laval, in northern Spain, in the Pyrenees, and in other localities in western Europe, where the Viséen alone is represented by marine beds. Even at Visé in Belgium, the Tournaisian is absent, the Viséen resting directly and disconformably upon the lower Upper Devonian (Frasnian), the Famennian too, being absent. The Tournaisian is likewise absent in England, but occurs in Ireland.

Dinantian of Asia.

Turning now to a consideration of the Dinantian of Asia, we find that here again the Viséen is most wide-spread, overlapping the Tournaisian. The latter has so far been found only in western and central Asia, none being known from east of the 90th meridian except for the Japanese occurrence, noted below. No Tournaisian is known within the Chinese basin, the oldest Carboniferous beds there being referable to the Viséen. This emphasizes the great transgressive movement of the sea in Viséen time (Map, Fig. 148).

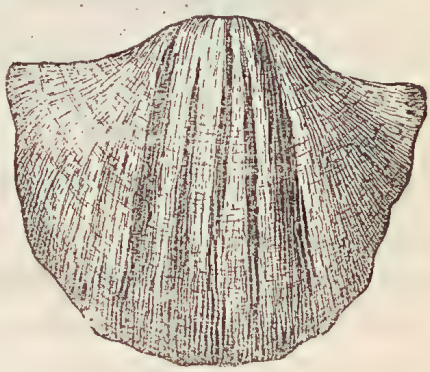

Fig. 149.
Productus giganteus Sow. Much reduced.

Eur-Asian Border. On the threshold of Asia, in the gorge of the Araxes on the Russo-Armenian and Persian border, the Dinantian series is complete, and is continuous with the underlying Devonian. In descending order the formations there are as follows (Frech 6, p. 294).

II Zone of *Productus giganteus* (Fig. 149).
Heavy-bedded partly bituminous and somewhat gypsiferous limestones with *Lonsdaleia*, echinoid

spines, *Productus semireticulatus* (Mart.), *P. keyserlingianus* de Kon., *Euomphalus* cf. *pentangulatus* etc.

I Zone of *Spirifer tornacensis* (Fig. 150).

I *b*. Marls and shales with abundant *Rhipidomella michelini*, *Athyris ambigua* Sow., *Orthotetes*

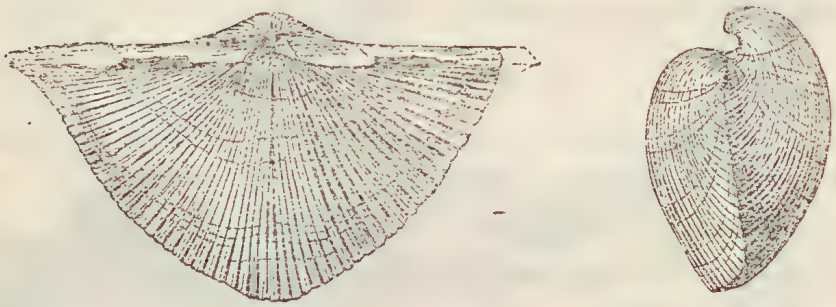

Fig. 150. *Spirifer tornacensis*.

crenistria, *Productus fallax* mut. *armenica* Frech, *Cyathaxonia cornu*, *Syringopora*, *Pentremites*, *Leptæna analoga* Phill., *Chonetes hardrensis* Phill., *Spiriferina moelleri* de Kon., *Athyris royssi* mut. *tornacensis* Frech.

I *a*. Marls and shales without, or rarely with *Rh. michelini*, but with *Productus fallax* mut. *armenica*, and *Athyris ambigua*, and more rarely *Rhynchonella pleurodon* Phill., and var. *davreuxiana* de Kon., *Leptæna analoga*, *Orthotetes crenistria*, var. *kelli* McCoy, etc. Also rarely from below *Spirifer tenticulum*.

Subformation: Upper Devonian black shales with *Spirifer verneuili* and variety *brodi* Wenj.

Dinantian strata are widespread in Asia Minor, being known from the Tauros and Anti-Tauros, as well as the Black Sea coast. In the Tauros, Viséen limestones with *Davisiella comoides*, *Spirifer bisulcatus*, etc., occur unconformably below the Cenomanian. Below the Viséen are unfossiliferous gray dolomites, and these are underlain by sandy marls with shaly limestones carrying *Spirifer tornacensis* and other fossils characteristic af the Tournaisian. These beds are, in turn, underlain by strata of middle Upper Devonian age. Viséen beds are also known from the Anti-Tauros, where they are represented by dark shaly limestones with *Pro. semireticulatus* Mart., *P. flemingii* Sow., etc. On the Black Sea coast, from the vicinity of Eregli north-eastward, Carboniferous beds are found to underlie the continental red shales and conglomerates of late Permian age (Rothliegendes), which themselves are overlain by the Cretaceous. Below the moderately folded coal-bearing Upper Carboniferous strata, occurs the Carboniferous Limestones with a rich fauna of Viséen age, including the following species: *Syringopora ramulosa*, *Productus giganteus* Sow., *Chonetes comoides* Sow. var., *Zaphrentis cylindrica* Scouler, *Lithostrotion irregulare* Phill., *Amplexus caralloides* Sow., *Monticulipora tumida* Phill., *Euomphalus dionysii* de Montf. Similar beds are found in the coal field of Amassa. Both in Tournaisien and Viseén time, Asia Minor appears to have formed the main line of communication between the European and central Asiatic water-bodies. The southern border of this connecting water-body appears to have extended across northern Syria, for the high peaks of the Duldul Dajh, to the south of the great gorge of the Dschihan (Jihun River) which forms the boundary line between Asia Minor and Syria, consist of great thicknesses of unfossiliferous limestones, which Frech considers to be of Dinantian age, though Schaffer and Keber refer them to the Turonian. On the International Geological Map of Europe, they are represented as Eocene. No Dinantian beds are

otherwise known from Syria, nor have they been found in Arabia, all these regions being apparently land in Dinantian time. The Mediterranean Sea, or Tethys, extended only to the border of this region for we find that on the Sinai peninsula a part of the Nubian sandstone contains limestone banks with numerous fossils of Lower Carboniferous age, but east of that region the oldest fossiliferous beds, included in the Nubian sandstone, are of late Carboniferous age.

Persia. Lower Carboniferous or Dinantian beds are well developed in northern Persia. They occur between Djulfa and Lake Urmiah, in the Elburz mountains, especially near Demavend, north of Teheran, extending eastward to Asterabad and Shahkuh. The general strike of the mountain systems today indicates the direction of the geosynclines in which these strata were deposited, this being for the region in question about E. N. E.

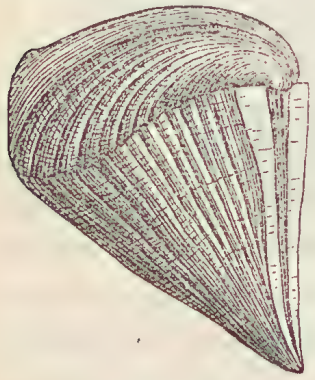

Fig. 151.
Syringothyris cuspidata Sow.

Both the Tournaisian and Viséen are represented in northern Persia, the former resting upon Upper Devonian limestones and containing Tournaisian fossils, including: *Spirifer tornacensis*, *S. striatus*, *Productus perlongus*, *P.* cf. *longispinus*, *P. semireticulatus*, *Euomphalus pentangulatus*, *Michelinia favosa*, *Orthotetes crenistria*, *Syringothyris cuspidatus*, *Martinia glaber*, *Rhynchonella pleurodon*, *Athyris royssi*. The Viséen is characterized by *Productus giganteus*, which has been obtained in at least one locality. Elsewhere in northern Persia, these limestones are characterized by *Martinia glaber*, *Productus punctatus*, *P. margaritaceus*, *P. semireticulatus*, *P. aculeatus*, *Dielasma hastata*, *Retzia buchiana*, *Spirifer triangularis*, *Hallia cylindrica*, *Syringopora* sp., *Zaphrentis* sp., and *Lithostrotion martini*. No Dinantian sediments are known in central and south Persia, but their occurrence is not excluded.

Turkestan. Of great interest is the discovery of a rich Lower Carboniferous fauna in the Ferghana region of eastern Turkestan. From this series 132 brachiopods have been described, 89 of which are positively identified. They include such characteristic Dinantian forms as *Rhipidomella michelini*, *Productus giganteus*, *P. costatus*, *P. longispinus*, *P. punctatus*, *P. striatus*, etc., *Chonetes papilionaceus*, *Rhynchonella pleurodon*, *Dielasma sacculus*, *Spirifer bisulcatus*, *S. duplicostatus*, *Martinia glaber*, *Spiriferina insculpta*, etc. The horizon represented is evidently Viséen. These beds are exposed on the northern and eastern slopes of the Alai-Plateau. At present the Tournaisian is not known to occur in Turkestan, although the great thickness of the limestones in the Alai chain suggests that it may be represented in the lower portion. In the western part of this region, the Dinantian beds lie unconformably upon the Upper Devonian, but in the eastern part the relationship is apparently a conformable one, although here too, there may be a disconformity.

Kwen-Lun, Tian-Shan. Lower Dinantian is not known with certainty from these mountains, although in the Karatau portion of the Tianshan, an enormous series of shales, sandstones and limestones, totalling some 3,000 meters, overlies the Devonian and carries Viseén fossils in its upper portion. The lower part contains *Productus semireticulatus*, *P. striatus* and *Spirifer striatus* and other fossils, and may well represent the Lower Dinantian. Aside from the localities mentioned, the Viséen everywhere in central Asia is found to rest unconformably or disconformably upon older formations, thus indicating the extent of the "Tianshan" transgression in Viséen time. Over extensive regions, the fauna of these beds is essentially of a uniform character, and frequently the Viséen limestones rest without clastic basement beds, directly upon the old rocks. In thickness this formation ranges from 500 meters in the Temurlyktau region, to more than 1000 meters in other parts of the Tianshan. It consists, for the

most part, of limestones of various colors, and varying composition from siliceous to dolomitic. Shales and sandstones are of subordinate development. In the Richthofen chain of the central Nan-shan carbonaceous shales with limestone lenses occur, but otherwise carbonaceous beds are not extensively developed. Faunistically the Viséen is characterized by the great abundance of *Productus*, among which the following forms are most conspicuous: *Productus giganteus*, *P. striatus*, *P. cora*, *P. undatus*, *P. hemisphæricus*, *P. aculeatus*, *P. spinulosus*, *P. semireticulatus*, *P. martini*, *P. costatus*, *P. pustulosus*, *P. punctatus*, *P. scabriculus*, *P. mesolobus*, *P. longispinus*, and *P. elegans*. Other characteristic brachiopods are: *Chonetes hardrensis*, *Martinia glabra*, *Reticularia lineata*, *Athyris expansa*, *Rhynchonella acuminata*, *Rhynchonella pleurodon*, *Dielasma hastatum* and *Cyrtina septosa*. Gastropods and pelecypods are also obtained locally, as are also corals. The latter include: *Lithostrotion irregulare*, *Syringopora ramosa*, *Cyathophyllum murchisoni*, *Dibunophyllum*. The greatest development of these beds is in the Tian-shan, that of the Kwenlun being much less extensive, indicating that probably the transgression was only partial in the Kwenlun region while the Tian-shan region was entirely covered by the sea. It is possible that the Kwenlun geosyncline was continued at this time in the Nanshan geosyncline, this being suggested by the Viséen beds of Bardoun in Kansu. On the other hand, it is possible that the passage way into China at this time, as in Permo-Carboniferous time, was by way of the southern geosyncline, i.e., that of the Himalayas. This is one of the problems that needs further extended investigation.

Sinkiang Province. In the western part of Sinkiang province, within the Tian-shan system, Viséen deposits are well developed and, since they fall within Chinese territory, they may be considered somewhat in detail. Several sections were described in detail by Krenkel (21) from this region:

(1) *Basch-sugun.* This lies north-east of Kashgar, in the valley system of the Kurumduk. The formations here consist of a stratum of greenish sandstone, followed by the very fossiliferous *Basch-sugun limestone.* The fossils indicate an upper Viséen horizon corresponding approximately to the *Dibunophyllum zone* of the English sub-division (p. 214). The following species have been identified from this section: *Orthis* (*Schizophoria*) *resupinata* Mart., *Productus tenuistriatus* Vern., *P. sinensis* Tschern., *P. subcostatus* Waag , (*P. costatus* Sow.), *P. semireticulatus* var. *martini* Sow., *P. semireticulatus* var. *transversalis* Tschern., *P. punctatus* Mart., *P. elegans* McCoy, *P. undatus* Defr., *P. pustulosus* Phill., *P. scabriculus* Mart., *P. humboldti* d'Orb., *P. aculeatus* Mart., *P.* cf. *spinulosus* Sow., *P. curvirostris* Schellw., *Spirifer crassus* de Kon., *S. marcoui* Waag., *S. rhomboidalis* McCoy, *Cyrtina septosa* Phill., *Reticularia lineata* Mart., *R. lineata* Mart. var. *elliptica* Phill., *Martinia glabra* Mart., *Rhynchonella* (*Pugnax*) *acuminata* Mart., *R. angulata* Linn., *Terebratula* (*Dielasma*) *hastata* Sow.

(2) *Chodschur-no-ussun.* Another section of the formations in the Tian-shan, is seen at Chodschur-no-ussun. The succession here is as follows in descending order:

4. Chiefly vari-colored tuffs with lava in the upper part, and occasionally intercalated bands of limestones, which carry few fossils.

3. Limestones, well bedded in the upper part, becoming more and more clayey and bituminous, with intercalations of tuffs; fossils at certain levels. The subdivision of this member is as follows:

d. Stratum with *Productus punctatus* and *Spirifer bisulcatus.*

c. Stratum with *Martinia glabra*, 50 cm.

b. Bed with *Conocardium*, 2 meters.

a. Green tuffs, 2 meters.

2. Massive heavy-bedded limestones, unfossiliferous at Chodschur-no-ussun but four to five kilometers eastward, what is apparently the same formation, has furnished fragments of *Productus cora* and *P. striatus*.

1. Thin platey grayish-green clay shales with occasional sandstone intercalations which contain plant remains; traversed by dikes of granite porphyry.

Among the species identified from these beds are the following: *Orthis* (*Schizophoria*) *resupinata* Mart., *Productus spiralis* Waag., *P. punctatus* Mart., *P. lineatus* Waag.? *P. striatus* Fischer v. Waldheim., *P. cora* d'Orb., *Chonetes hardrensis* Phill., *Spiriferina cristata* v. Schloth., *Spirifer bisulcatus* Sow., *Martinia glabra* Mart., *Edmondia sp.*, *Aviculopecten sp.*, *Parallelodon sp.*, *Conocardium aliforme* Sow., *Loxonema sp.*, *Phillipsia sp.*, *Orthoceras sp.*

Yulduz. In the central part of the valley of the Little Yulduz River (ab't Lat. 43°N. Long. 85°E.) between Kuldja and Karashar, the Upper Dinantian limestones are found to rest unconformably upon ancient phyllites. The section of the formations is as follows in descending order.

d. Heavy-bedded limestones with few flints...25 meters.

c. Platey limestones with numerous flints.....15 meters.

b. Gray, well-bedded limestones with inter-bedded red crinoidal limestones becoming in the upper part very heavy-bedded gray and violet limestones with indistinct bedding. Flints numerous.....40 to 50 meters.

a. Heavy-bedded reddish-violet and gray crinoidal limestones with numerous fossils.....20 meters.

Unconformity

Ancient phyllites.

At another point, in the same valley, the section is as follows:

7. Siliceous limestones with corals and *Spirifer bisulcatus*.....50 meters.
6. White and reddish homogeneous limestones with *Athyris*.....10 meters.
5. Gray spotted limestones with many *Productus*, unfossiliferous in the upper part, passing downward into 4.,.....100 meters.
4. Reddish bedded limestones with *Productus striatus*.....10 meters.
3. Gray, more seldom reddish, limestones with siliceous layers.....50 meters.
2. Limestones with flints and with gigantic *Productus* in the upper part..... 30 to 40 meters.
1. White granular crystalline massive limestones with few fossils.....30 to 40 meters.

The fossils obtained from this section include the following species: *Productus cora* d'Orb , *P. giganteus* Sow. var. *edelburgensis* Phill., *P. striatus* Fischer, *P. inflatus* McChesney, *Spirifer duplicicosta* Phill., *Camarophoria* cf. *globulina* Phill., *Athyris* sp.

(4) *Borobogussun.* In this section the Dinantian series is not especially thick and consists mainly of limestones, tuffs and tuffaceous limestones, resembling in this respect the succession of Chodschur-no-ussun. The following horizons have been differentiated, in descending order:

f. Beds with small pelecypods and corals.
e. Green and gray unfossiliferous tuffs, 10 meters.
d. Limestones with *Cyathophyllum murchisoni*, 3 meters.

Interval.

c. Tuffaceous limestones with marine fossils and remains of *Lepidodendron;* clay limestones with *Bellerophon*. *Interval.*

b. Beds with *Modiolopsis* and *Productus semireticulatus*. *Interval.*

a. Beds with *Productus cora*. The beds dip about 30° to the south.

The following species have been identified from this section: *Syringopora ramulosa* Goldf., *Clisiophyllum* sp., *Cyathophyllum murchisoni* Edw. and Haime, *Productus cora* d'Orb., *Spiriferina cristata* v. Schloth., *Martinia triquetra* Gemm. (var. *pentagona* Gröber), *Dielasma* sp., *Aviculopecten dissimilis* Flemm., *Aviculopecten* sp., *Limatulina desquamata* McCoy, *Modiola sp.*, *Posidoniella sp.*, *Lithodomus* cf. *carbonarius* Hinde, *Cypricardella sp.*, *Sanguinolites tricostatus* Portl., *Bellerophon tenuifascia* Sow.

Utsch-turfan. (*Uch-Turfan*, Lat. 41°6′ N. Long. 79°10′ E.) This city lies on the right bank of the Kokshal River or better, its continuation, the Taushkan river, and an affluent of the Tarim. It is bounded on the south by a rocky ridge, which rises up to 400 meters in height. This ridge consists of three formations, dark brown crinoidal limestones, gray violet dolomitic limestones, and platey bedded yellowish gray sandstones. Limestones and sandstones alternate, the former being most abundant in the lower, and the latter in the higher part. *Productus giganteus* is found in the limestone and in the sandstone, in the latter, however, only sparingly. South of the city, the entire series is folded. West of the Chinese city lies the hill Kusch-tagh, which rises directly from the loess plain to a height of 20 to 30 meters and extends in a general east-west direction. It is crowned by a Chinese pagoda. The hill consists of nearly horizontal limestone layers, some of which are composed entirely of brachiopods,

chiefly *Productus giganteus*. These beds probably belong below those of the before-mentioned ridge, to the south of the city. The following species have been obtained from the fossiliferous limestone of the Pagoda hill: *Productus giganteus* (Mart.) Sow., *Productus sp.*, *P. hemisphæricus* Sow., *P. gröberi* Krenkel, *P. pustulosus* Phill, *P. semireticulatus* Mart., *Spirijerina cristata* v. Schloth., *Orthothetes* (*Schellwienella*) *crenistria* Phill.

In the northern part of the central Tian-shan, Lower Carboniferous limestones are also found resting transgressively upon the older rocks. The oldest sedimentary rocks in this region are phyllites and clay slates, both of them being referred to the Palæozoic. The phyllite appears to pass gradually into the clay slates. Upon this older series rests the Lower Carboniferous limestone, which has a wider distribution in this region than the older sediments, not infrequently resting upon the crystallines, especially the granites. It represents a deposit formed by the transgressing sea and in most places, it is characterized by a basal conglomerate, which is sometimes calcareous. This limestone is especially characterized by *Productus giganteus* and *P. striatus*, as well as many corals. Where it is in igneous contact with granite or other intrusive rocks, it is highly metamorphosed and its fossils are destroyed. Two facies of this limestones are generally found: a dense dark gray, often dolomitic limestone, and another crinoidal limestone. These rocks form the high peaks of the range, rising in the peak Nicolai-Michailowitch to a height of more than 6000 meters. *Productus giganteus* and *P. striatus* are common in the dark dolomitic limestone, together with large single corals and compound heads of *Syringopora* and *Lithostrotion*. The crinoidal limestone also contains the two species of *Productus* but corals are less characteristic of it. The limestones are overlain by vari-coloured platey marls, gray and green marl clay and gypsiferous red sandstones and conglomerates. These form the youngest Palæozoic

sediments of the region and probably represent regressive or continental deposits of Middle and Later Carboniferous time. (Keidel & St. Richarz 19).

From the vicinity of the Sart-dschol Pass, southeast of Karkara, in the northern Central Tian-shan, the following fauna has been obtained, partly from black limestone in which fossils are silicified, partly from red sandy limestone which contains mixtures of granitic debris, and from red to white limestones (Gröber 15): *Endothyra*, *Textularia*, *Zaphrentis* sp., *Lithostrotion irregulare* Phill., *Cyathaxonia dissimilis* Gröber., *Streptorhynchus* sp., *Derbya?*, *Chonetes papilionacea* Phill., *Productus giganteus* Mart. var. *edelburgensis* Phill., *P. striatus* Fischer, *P. margaritaceus* Phill., *P. cora* d'Orb. var. *kok-dscharensis* Gröber., *P. longispinus* Sow., *Schizophoria resupinata* (Mart.), *Camarophoria globulina* Phill., *Athyris expansa* Phill., *Spirifer bisulcatus* Sow., *Martinia decora* Phill., *M. triquetra* Gemm. var. *pentagona* Gröber, *Reticularia lineata* Mart., *Dielasma* sp., *Loxonema sulcifera* de Koninck?

Further east, in the Tian-shan (in Chalytau, Temurlyktau, Dsungarian Alatau) between long. 80° and 83° and lat. 42° and 43° these limestones form a portion of the central zone of the mountains, including part of the high Tengri-khan. In this region, however, the limestone is generally altered to a granular marble ranging from various shades of yellow to dark gray in colour. Many new minerals have been formed, especially mica, tourmaline, and quartz veins. Fossils are of course not present in this metamorphic rock but these have been found in the outer zone where the rock was less altered. As usual *Productus giganteus* predominates. These limestones throughout the entire northern range, are found to rest unconformably upon the older phyllites and they are disconformably succeeded by late Palæozoic and Mesozoic continental beds. The thickness of the Carboniferous

limestone is at least 600 meters and, so far as known, the whole belongs to the later part of the Dinantian. (Leuchs 22).

The following species, found in the Carboniferous limestones, especially the Dibunophyllum zone of England, also occur in the upper Viséen beds of the Tian-shan (Krenkel 21).

Corals: *Cyathophyllum murchisoni* E. & H., *Lonsdaleia* aff. *floriformis* Flem., *Syringopora ramulosa* Goldf., *Lithostrotion irregulare* Phill., *Dibunophyllum* aff. *ψ* Vaugh.

Brachiopods: *Schizophoria resupinata* Mart., *Productus giganteus* Sow. (with var.), *P. hemisphæricus* Sow., *P. pustulosus* Phill., *P. punctatus* Mart., *P. longispinus* Sow., *P. semireticulatus* Sow., *P. martini* Sow., *P. costatus* Sow., *P. scabriculus* Mart., *P. aculeatus* Mart., *P. spinulosus* Sow., *P. mesolobus* Phill., *P. cora* d'Orb., *P. striatus* Fisch., *P. undatus* Defr., *Chonetes hardrensis* Phill., *C. papilionacea* Phill., *Spirifer bisulcatus* Sow., *S. duplicicosta* Phill., *Martinia glabra* Mart., *Reticularia lineata* Mart., *Athyris* cf. *royssi* l'Ev., *A. expansa* Phill., *Cyrtina septosa* Phill., *Camarophoria globulina* Phill., *Rhynchonella acuminata* Mart., *R.* cf. *pleurodon* Phill., *Dielasma hastata* Sow.

Siberia. Dinantian rocks are known from two regions in western Siberia; that of the Kirghiz elevation, and that of the Government of Tomsk, south of the Trans-Siberian Railway line. In the former region, they are found in a number of scattered districts, resting upon the Devonian or uncomformably upon the crystalline rocks. In the Government of Tomsk, the Dinantian beds are especially well developed in the Kusnezk coal basin, where they rest upon Devonian rocks. In both regions, they are of very similar character, consisting primarily of limestones, usually gray, and typically crystal-

line. They are succeeded by sandy clays with subordinate coal beds, representing the higher Carboniferous. The limestones, especially those of the Kirghiz Steppes, are rich in organic remains, including the following species: *Productus semireticulatus* Mart., *P. pustulosus* Phill., *Spirifer tornacensis* de Kon., *S. duplicostatus* Phill., *S. bisulcatus* Sow., *Syringothyris cuspidata* Mart., *Reticularia lineata* Mart., *Orthis* (*Schizophoria*) *resupinata* Mart., *Rhynchonella pleurodon* Phill., etc. From this list it is evident that both the Tournaisian and the Viséen are represented in this region.

Mongolia. Farther to the south-east in Mongolia in Lat. 44° 43′ North, and between Long. 107° 30′ and 108° East, Professors Berkey and Morris, of the Third Asiatic Expedition of the Museum of Natural History, New York, have discovered folded limestones with fossils, indicating the presence of the Viséen. Among the fossils so far identified from these deposits are the following.

From limestones east of Sair Usu: *Michelinia* cf. *favosa*, *Cladochonus* sp., *Schizophoria resupinata*, *Rhipidomella* cf. *michelini*, *Spirifer* cf. *trigonalis*, and cf. *Productus giganteus*.

Japan. That this Mongolian geosyncline extended to the Pacific coast, permitting migration of the marine organisms along it to western North America is shown by the presence of *Productus giganteus* and *P. latissimus*, and associated species, in the Baird shales of the Sierra Nevada in California. It is again shown by the recent discovery of late Dinantian faunas in the Upper Palæozoic limestone series of Japan, especially at Omi-Mura in the province of Echigo.* (Hayasaka 16). The fauna includes corals (*Echigophyllum*, *Lonsdaleia*, *Axophyllum*, etc.), and brachiopods (*Camarophoria globulina*, *Spirifer duplicostatus*, *S. humerosus*, *Reticularia lineata*, *R. elliptica*, *Pugnax acuminata*, *P. pugnus*, *Syringothyris cuspidatus*,

* Exact position and locality unknown.

etc.). The last named species suggests Lower Dinantian or Tournaisian, but the bulk of the fauna, according to Hayasaka, must be regarded as representing the Viséen. From the Kitakami mountains in the north of Japan, corals of Dinantian affinities have been obtained (*Lonsdaleia japonica, Lithostrotion pseudomartini, Diphyphyllum flexuosum*), thus suggesting a very wide distribution of Dinantian faunas in the Palæozoic rocks of Japan.

Himalayan Geosyncline. Returning to southern Asia, we should expect to find a well-developed series of formations representing the Lower Carboniferous or Dinantian in the Himalayan geosyncline, because this represents the most probable passage-way along which the Viséen fauna could have entered the Chinese basin, since we find the fauna so extensively developed in south China. That beds of this age are wide-spread in the Himalayan Palæozoic is generally believed, though very little is as yet known of them.

In Spiti, the Muth quartzite, a continental series of great thickness, and resting directly upon the Silurian (See p. 117) is overlain by the Lipak Series, a succession of limestones and quartzites more than 2,000 feet in thickness. The limestones abound in fossils, the fossiliferous bands alternating with white and gray barren quartzites. The fossils of the limestones are characteristic Lower Carboniferous species, indicating the presence, not only of the Viséen, but also of the Tournaisian, the latter being indicated by the occurrence of *Syringothyris cuspidata* (Fig. 151, p. 229). Other characteristic species are *Productus cora*, *P. semireticulatus*, *Athyris royssi*, and species of *Chonetes*, *Spirifer*, *Reticularia*, and of *Conocardium*, *Aviculopecten*, *Phillipsia*, *Orthoceras*, etc.

The Lipak series is followed with apparent conformity by the Po Series of shales of Middle and Upper Carboniferous age. These two are generally classed together as the Kanawar System, and are followed disconformably by the Permian.

Dinantian of the Chinese Basin.

Dinantian strata are wide-spread within the Chinese basin, which includes China proper, and the northern provinces of Indo-China.* Two divisions are recognizable, namely the Viséen and a higher division which has been designated the *Taiyuan Series* from its typical development in the vicinity of Taiyuan-Fu in central Shansi.

Fig. 152. *Spirifer bisulcatus* Sow.

There is no evidence that the Lower Dinantian or Tournaisian sea entered the Chinese basin. The beds which have been regarded as representing this horizon in Yunnan carry fossils of strictly Viséen age, and it is therefore held that the Chinese basin was first

Fig. 153. *Enteletes lamarcki* Fischer de Waldh.

flooded by the transgressing Viséen sea. This flooding may have been by way of the Himalayan geosyncline, for true Viséen rocks seem to be largely restricted to southern and central China. Nevertheless it is possible that the Viséen waters entered the Chinese basin along the northern or Nanshan geosyncline and its continuation in the Tsingling geosyncline, for true Viséen beds seem to be well developed in the Bardoun region of western Kansu.

Fig. 154. *Phillipsia kansuensis* Loczy. Pygidium × 3.

* The Dinantian of western Sinkiang Province has been described above (p. 226).

It was, however, during the Taiyuan epoch that the greatest spread of the sea occurred in the Chinese basin (Fig. 221), this covering the greater part of north China and extending through the Nanshan geosyncline west to the central Asiatic district. The marine beds of the Taiyuan series of north China occur in the form of thin intercalations of limestone in the continental coal-bearing sands and shales of the series. They are most extensively developed in the central region (central Shansi) where eight successive horizons are recognized. Westward only the lower members are found, the lowest one alone being recognized in western Kansu. This absence of the higher beds may of course be due to erosion during Mid and early Upper Carboniferous time. (Norin 33; Wang VIII, 71.)

Fig. 155. *Loxonema szechenyii* Loczy.

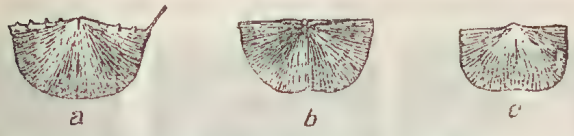

Fig. 156. *Chonetes nyströmi* Grabau; *a*, pedicle valve; *b*, brachial valve; *c*, mold of interior of pedicle valve.

In south China, on the other hand, the Taiyuan series is represented by limestones of considerable thickness.

The fauna of the Taiyuan series is a remarkable mixture of Dinantian species with those generally recognized as belonging to the Moscovian. Foremost among

Fig. 157. *Lopholasma carbonaria* Grabau. Three successive sections (somewhat oblique) of a typical specimen enlarged, (first and third sections are reversed; middle section in normal orientation).

the species characterizing the fauna, is *Spirifer bisulcatus* (Fig. 152) while *Sp. duplicostata* is less common. With these in the lowest members occur *Spirifer pankouensis* Grabau, *Enteletes lamarckii* (Fig. 153), *Phillipsia kansuensis* (Fig. 154), *Loxonema szechenyii* Loczy (Fig. 155), etc. Other members are characterized by *Productus taiyuanfuensis* Gr., *P. punctatus*, and var. *elegans*, *P. scabriculus* and *P. cora*, *Chonetes* (*C. nyströmi* (Fig. 156), *Athyris*, *Reticularia* (*R. lineata* etc.), *Spiriferina*, *Hustedtia* and other brachiopods. The pelecypods include a number of new species of *Aviculopecten*, *Acanthopecten* and *Entolium*, and the gastropods include *Euphemus orbignyi*, *Cyclonema carbonaria*, *Macrocheilus*, *Naticopsis* etc. Characteristic corals of the central

Fig. 158.
Lophocarinophyllum acanthiseptum Grabau, natural size, and enlargement of slightly worn surface, showing carinæ.

Fig. 159 *Lophocarinophyllum acanthiseptum* Grabau. A series of slightly oblique, transverse sections showing development of septa and pseudocolumella, (enlarged about 2½ times). The first and third are normally oriented; the second and fourth are reversed in position. The final figure represents a median longitudinal section, showing the thickened pseudocolumella, and the *Lopholasma*-like character of the carinæ, which appear here as horizontal lines. (Enlarged x3).

region (central Shansi) are *Lopholasma carbonaria* Grabau (Fig. 157), *Lophocarinophyllum acanthiseptum* Gr. (Fig. 158, 159), and *Pinnatophyllum norini* Gr. (Fig. 160) (Grabau 13), while in the more easterly region in the Tangshan limestone, *Alveolites tangshanensis* Gr. and *Lithostrotion kaipingense* Gr. (Fig. 161) are dominant.

The Foraminifera are mainly of species at home in the typical Dinantian, the following species being frequent both in Viséen and Taiyuan rocks of China:

Fusulinella struvii Möll; *Fusulinella loczyi* Lörenthy (Figs. 162 a, b.); *Spirillina irregularis* Möll; *Sp. plana* var. *patella* Lörenthy (Figs. 162 e, f.); *Sp. subangulata* Möll; *Sp. chinensis* Lörenthy (Figs. 162 c, d.); *Tetrataxis conica* Ehrenb. (Figs. 163 a, b.); *T. conica* var. *gibba* Möll; *Endothyra parva* Möll. (Fig. 163 c,); *E. bowmanni* Phill. (Figs. 163 d, e.); *Cribrospira panderi* Möll. (Fig. 163 f.); *Climacammina eximia* Brady (Figs. 163 g, h.); *C. bradyi* Möll; *Lingulina szechenyii* Lorenthy (Fig. 164).

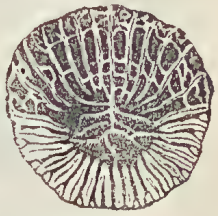

Fig. 160. *Pinnatophyllum norini* Grabau, cross-section.

The fauna as developed in western Kansu, was originally described by von Loczy, and by him referred to the Middle Carboniferous or Moscovian. This was due to the fact that von Loczy identified the large *Spirifer* which is characteristic of that bed, as *Spirifer mosquensis* a mistaken identification as is shown by a study of an extensive series of these fossils recently received from that section. The species is a modification of the typical *S. bisulcatus* of the normal Taiyuan series, differing primarily in the flattening of the costæ in the later stages of growth. In the young the form has all the characteristics of the normal form of the species, to a variety of which it is referred (var. *kansuensis* Gr.). There is every indication, however, that this variety was ancestral to the true *S. mosquensis* (Fig. 184) the young of which

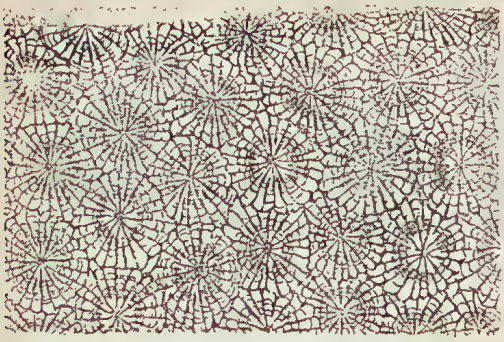

Fig. 161. *Lithostrotion kaipingense* Grabau, cross-section, × 2.

closely resembles the adult of the Kansu form. Indeed the suggestion is presented, that the Taiyuan fauna, itself a modified derivative of the Viséen, developed within the circumscribed basin of China under

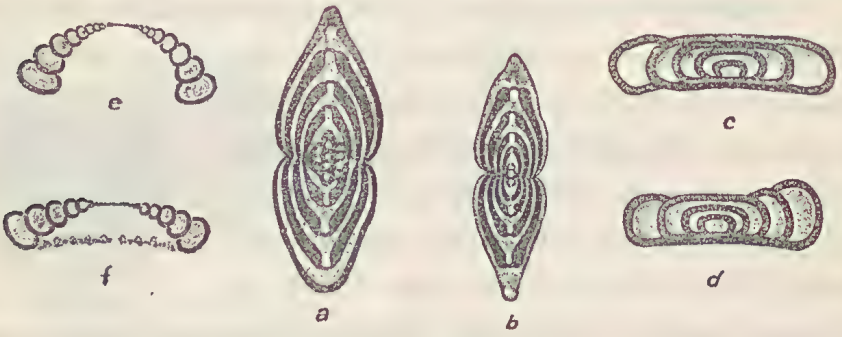

Fig. 162. Sections of Foraminifera from rocks of the Taiyuan series, enlarged; *a-b. Fusulinella loczyi* Lör.; *c-d, Spirillina chinensis* Lör.; *e-f, Spirillina plana*, var. *patella* Lörenthy.

conditions of isolation, was in turn the ancestor of the true Moscovian fauna, which developed from migrants of the Taiyuan fauna of China, and reached its greatest differentiation in the central Russian basin.

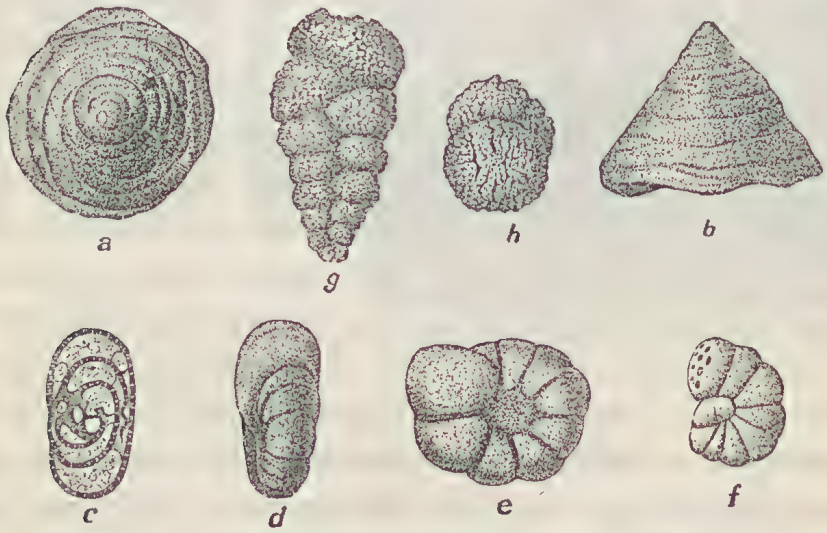

Fig. 163. Foraminifera of the Viséen and Taiyuan beds of China, all much enlarged. *a-b, Tetrataxis conica* Ehrenb. top and side views × 36; *c, Endothyra parva* Möll, cross-section × 75; *d-e, Endothyra bowmanni* Phill. × 38; *f, Cribrospira panderi* Möll., × 7½, *g-h, Climacammina eximia* Brady, side and top views, × 22½.

This can of course be nothing more than a suggestion at present, the demonstration or refutation of which must await the detailed and comparative studies of these faunas based primarily on the ontogeny of the individual elements. Preliminary studies of these Spirifers seem to point to the derivation of the typical *S. mosquensis* from *S. bisulcatus* through such intermediate forms as *S. bisulcatus* var. *kansuensis*.

What is true of the Kansu form referred by von Loczy to *S. mosquensis* is equally true of the species referred by Mansuy to the same form in eastern Yunnan. Here the modification of the costæ is in the same direction, while the form on the other hand remains extended transversely. This too is a variety of *S. bisulcatus* (var. *weiningensis* Gr.) as is shown by a study of the young shells, and the limestones in which it occurs are referred to the Taiyuan series. (See below).

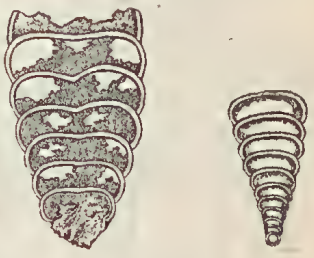

Fig. 164.

Lingulina szechenyii Lörenthy. *a*, longitudinal section parallel to broad side; *b*, longitudinal section parallel to narrow side. Much enlarged.

We might of course refer the entire Taiyuan series to the basal part of the Moscovian, but since it marks the culmination of the trangressive movement begun in China in the Viséen epoch, whereas the typical Moscovian was in China a period of emergence, it seems more logical to class it as the final stage of the Dinantian, especially since, in its typical development, it carries a proponderating Dinantian element in its fauna. The presence of *Fusulina* in this fauna need not modify this classification, since it is obvious that *Fusulina* could not have arisen suddenly at the beginning of Moscovian time, it must have had a pre-Moscovian history of some duration during which it developed, probably from some *Endothyra*-like ancestor. It is not improbable that this development took place within the Chinese basin during the Taiyuan epoch.

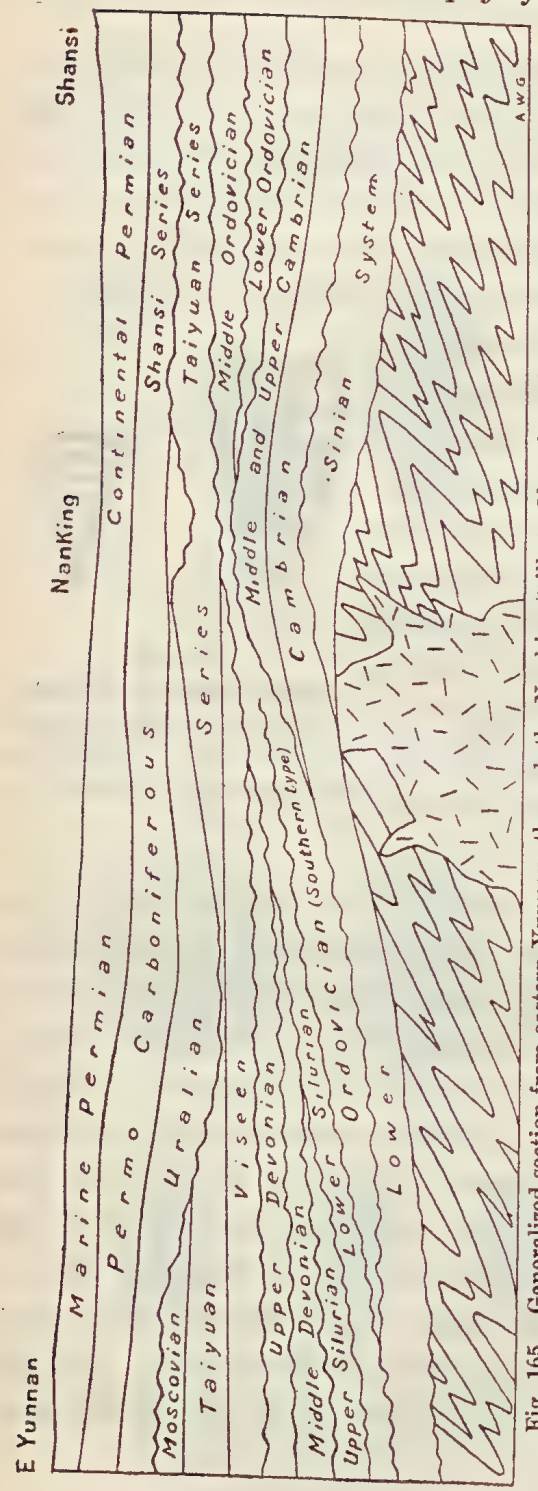

Fig. 165. Generalized section from eastern Yunnan, through the Nanking Hills to Shansi, to show the relationships of the Palæozoic strata. (Wavy lines indicate disconformities. Ordovician should be continuous, Silurian not.)

In any case, the Taiyuan series, if Moscovian, can represent only a very short portion of that period, the greater part of which is unrepresented in China. The study of the plants of the Taiyuan series, which is now under way, will serve to throw further light on this problem.

Throughout north China, the Taiyuan beds are disconformably succeeded by beds of Permo-Carboniferous age (*Shansi series*), which contain a few marine members, but are chiefly of continental origin. Considerable erosion took place, after the retreat of the sea at the end of Dinantian time, so that the succeeding beds rest upon various members of the older series. In Yunnan and some other portions of south China on the other hand, extensive marine Carbonic beds were

deposited, showing that the sea continued to linger there. A generalized cross-section from south to north represents approximately these relationships. (Fig. 165). Further details are given below.

Dinantian of South China and Indo-China.

YUNNAN. In Eastern Yunnan, Deprat and Mansuy have established the following succession for the lower beds of the Carboniferous series. (Fig. 166).*

Div. B. VI	*Choueitang Limestone*	100 meters
Div. B. V	*Loatien Limestone*	80 ,,
Div. B. IV	*Eulkai Group*	86 to 270 ,,
	Comprising:	
	Upper limestone series	40 - 120 m.
	Shales	6 - 50 m.
	Lower limestone and shale series	80 - 100 m.
Div. B. III	*Laowatong Group.* Continental sands, arkoses, red beds and volcanics	96 to 350 meters
Div. B. II	*Chatchong Limestone*	,,
Div. B. I	*Continental Group.* Sands, cross-bedded etc	250 to 300 ,,
	Total of Div. B. 600 to 1,100 meters or more.	
	Hiatus? and Disconformity?	
Div. A. IV	*Toumounyi Series.* Limestone	? meters
Div. A. III	*Hoakeuou Series.* Marly shales	110 ,,
Div A. II	*Tiensenkouang Series.* Calcareous and marly shales	? meters
Div. A. I	*Hoangitien Series.* Sandstones and marls with fossils	over 200 meters
	Total Div. A. 400 meters or more.	

* The lettering of the series is added.

The most characteristic fossils of Division A. I-IV, are brachiopods, most of which are identical with, or closely related to species which occur in Europe in the upper division of the Dinantian, i.e., the Viséen. This is also true of the other fossils, in so far as they have been identified. No representatives of the species characteristic of the Middle and Lower Divisions, i.e., the Tournaisian and Etroeungtian of western Europe are present, and this shows that the lowest divisions of the Yunnan Dinantian are Upper Dinantian, even those of Div. A. I. The more typical forms include *Chonetes papillionaceus* Phill. (Fig. 167), *Spirifer subconicus* Mart., *Spiriferina insculpta* Phill., and various species of *Productus*. Some corals also occur.

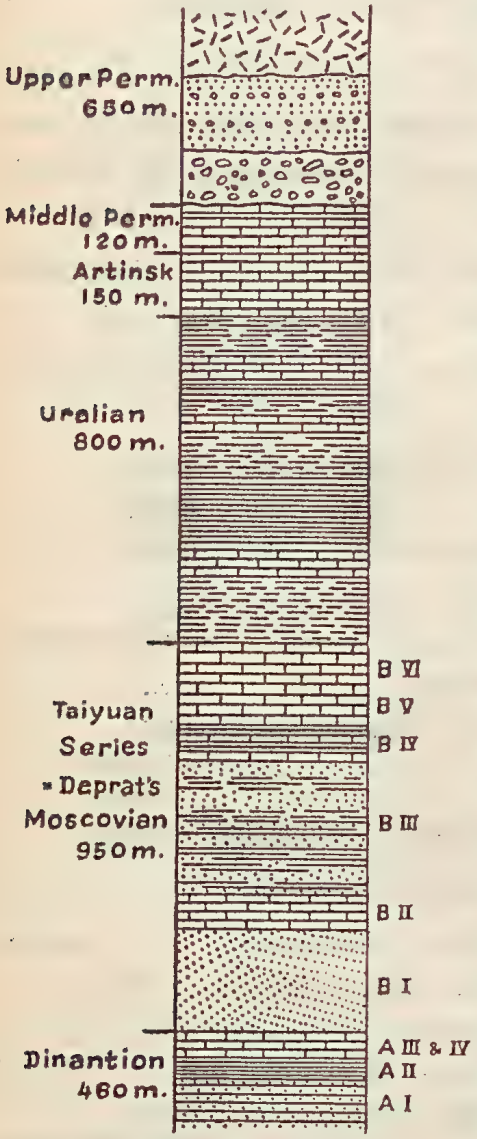

Fig. 166.

Columnar section of the Dinantian, Uralian and Permian of eastern Yunnan, from data given by Deprat. The classification is the one adopted in the text, and the notation on the right is that used in describing the successive formations.

The succeeding beds of Div. B., especially B. II and B. IV, abound in Foraminifera, including characteristic Dinantian species. Practically all the species obtained in these beds also occur in the Taiyuan series of north China, with which this division is correlated. Among the brachiopods found in Div. B. IV, is one

referred by Mansuy to *Spirifer mosquensis* Fischer, the characteristic fossil of the Middle Carboniferous or Moscovian of Russia. The Chinese form is, however, not this species, but, as already noted, a

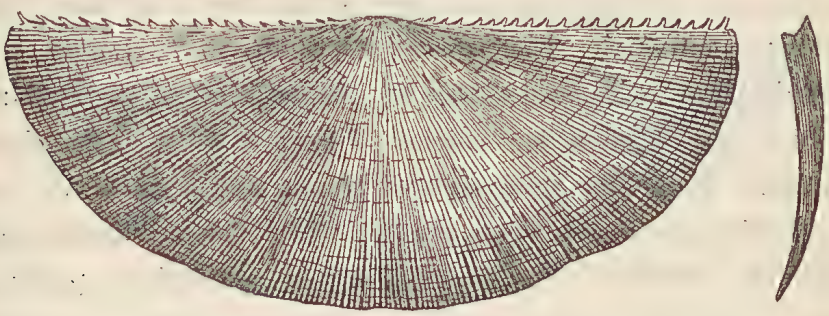

Fig. 167. *Chonetes papilionaceus* Phill. Average large form.

variety of *Spirifer bisulcatus* Sow. (variety *weiningensis* Grabau), the most typical and widespread brachiopod of the Taiyuan series of north China, and a characteristic Dinantian species of Europe. The

Fig. 168. *Productus yunnanensis* Loczy. Imperfect specimen (type).

other brachiopods identified from this division by Mansuy are also found in the Viséen of Europe. It is noteworthy, that the Chatchong limestone (B. II) is separated from the upper limestones of Div. A I

by a great thickness of continental sands, and by a similar series from the succeeding Eulkai marine group (B. IV).

More recently Mansuy (VI, 45) has described a faunule from the limestones of Eul-Kai in E. Yunnan which clearly indicates Viséen or Taiyuan affinities. The species described are: *Amplexus* cf. *coralloides* Sow., *Archæocidaris* (?), *Athyris eulkayensis* Mans., suggestive of a Tournaisian species, *A.* cf. *subtilita* Hall, also a Tournaisian form; *Mourlonia colanii* Mans., and *Murchisonia yunnanensis* Mans., two species of younger Carboniferous affinities, and *Microdomus biserratus* Phillips, an Upper Dinantian species of Europe.

Further east, in the Kütsing region of east Yunnan, Viséen beds rest, according to Dr. V. K. Ting, directly and disconformably upon Middle Devonian. Such characteristic fossils as *Productus giganteus*, *P.* cf. *cora*, *P. semireticulatus*, *Chonetes papilionaceus*, etc. are found in these beds. In Tungshan (Fig. 120. p. 189) the Middle Devonian appears to be directly but disconformably overlain by shales, sandstones and limestones of the Taiyuan series. These contain *Pinnatophyllum norini* Grabau, *Cladochonus?* sp., *Rhipidomella* cf. *michelini*, *Composita* cf. *argentea*, and *Septopora biserialis*. Faulted against these are light-colored calcilutytes of Uralian or Permo-Carboniferous age with *Fusulina*.

In the Weining region, late Viséen limestones (Weining limestone) and limestones of the Taiyuan series appear to be well developed. Among the fossils collected by Dr. Ting, the following may be noted: *Spirifer bisulcatus* var. *weiningensis* Grabau, *Productus giganteus*, *P.* cf. *undatus*, *P. lineatus*, *Diclasma* sp., etc. Limestones with *Lithostrotion kaipingense* Grabau and *Productus mytiloides* also occur.

So far, then, as our knowledge of eastern Yunnan permits us to judge, the Dinantian begins with beds of Viséen age, which rest

disconformably upon Upper Devonian (probably Frasnian), the Tournaisian and older Dinantian beds being entirely wanting. The Viséen is succeeded conformably by sandstones and limestones of the Taiyuan series, above which only a local representation of the Middle Carboniferous or Moscovian is found, the succeeding series being more generally of Uralian age.

Fig. 169.
Chonetes hardrensis Phillips.

From western Yunnan, von Loczy has described a fauna obtained from yellowish-gray, calcareous sandstone, from which the lime has mostly been leached, and which occurs at Talichou near Young-chou-fu. This fauna comprises the following species. Corals: *Zaphrentis beyrichi* Rothpl. Brachiopods: *Productus yunnanensis* Loczy (Fig. 168), *P. punctatus* var. *elegans* McCoy, *Chonetes papilionaceus* Phill. (Fig. 167), *Schellwienella crenistria* (Phill.). Foraminifera: *Fusulina* sp., and all except the second and last three of the species listed on p. 239.

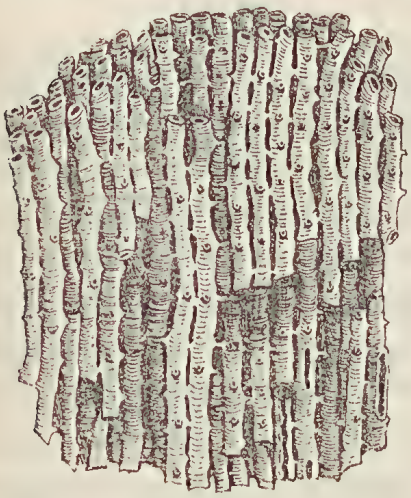

Fig. 170.
Syringopora geniculata Phillips.

The presence of *Ch. papilionaceus* and *Zaphrentis beyrichi* suggest that this horizon is Viséen, but it may also represent the Taiyuan series, though no absolutely distinctive forms of that series, except the Foraminifera have been recorded.

Indo-China. Beds of Viséen age appear to be well developed in Tonking, Laos and north Annam in Indo-China (Mansuy 27-29). In the Tranninh distinct of Laos, at Nong-Po, a fauna of typical Viséen character is found in calcareous shales, this comprising

in addition to a number of new species, such characteristic European forms as *Chonetes hardrensis* Phill. (Fig. 169), *Schellwienella crenistria* (Phill.), *Schizophoria resupinata* (Martin), and *Spirifer bisulcatus* Sow. (Fig. 152). At Ban-Van-Ka, Upper Laos, limestones with *Schellwienella crenistria* var. *cylindrica* McCoy and gastropods have been obtained. In Elephant Mountain, near Hai-phong, Tonking, black limestones with a typical Viséen fauna have been discovered. The fauna consists mostly of new species but includes *Syringopora geniculata* Phill. (Fig. 170), and two other (new) species; *Productella*, related to *P. spinulosa* Sow., and *P. aculeata* Martin, and new species of *Spirifer* and *Athyris* related to European Dinantian forms. A number of gastropods, including *Euomphalus crotalostomus* McCoy, and four species of *Baylea* related to Viséen species of Europe, also occur.

In the Thonh-ba district of Tonking (between Lang-chiet and Bancai), calcareous shales with corals and brachiopods of Dinantian affinities are found, but most of the species are either new, or the specific identity is not certain. Nevertheless, the general aspect of the fauna is that of a Dinantian one. In the Laichan limestone of Muong-Tham, east of Lai-Chan, a species of *Lithostrotion* is common, which appears to have close affinities with *L. irregulare* (Phillips) of the European Viséen. In the Yen-Minh district of Tonking, limestones with *Productus scabriculus* Mart., *P. cora* d'Orb. and *Marginifera* cf. *involuta* Tschern. are found, and these may also represent late Viséen, or they may belong to the Taiyuan series.

Finally in North Annam, between Bai-duct and Phuc-trach, have been found shales with trilobites of the genus *Phillipsia*, i.e., *P. propinqua* Mans., closely related to *P. gemmulifera* Phill., and *P. pustulata* Schloth. of the European Viséen.

The stratigraphy of Indo-China is very involved, and the preliminary work of Deprat is now undergoing revision by the Geological Survey of that country. At present, therefore, we only know that the Viséen is typically developed in the north of Indo-China. Whether the Taiyuan series is present or not, can not be satisfactorily determined from these fossil lists.

Fig. 171. Cross-section of Chihsia-Shan near Nanking (Nanking Hills) (after Ting and Yih). 1. Quartzose sandstone; 2. Shales and sandstones (coal?); 3. Conglomerate; 4. Chihsiashan limestoue; 5. Covered by Alluvium; 6. Quartzite (Wutungshan quartzite). No. 1 may be repetition of part of No. 6 through faulting or close folding.

From the Patalung district of Lower Siam (Malay Peninsula), beds with fossils of the *Posidonia becheri* zone (Culm) (See *ante* p. 214) have been described by Reed. These may represent the Taiyuan transgression. They will be again referred to in the next chapter.

Szechuan. The Viséen is again known from the region south of Chungking in southeastern Szechuan, near the Kweichow border (Frech 7). Here the more or less disturbed beds, with dips up to 50° northward, consist of sandstones, shales and limestones. Some of the softer sandstones and limestones contain a marine fauna of characteristic Viséen species, including *Martinia glaber* var. *symmetrica*, *Athyris ambigua*, *Schizophoria resupinata*, *Productus semireticulatus*, *P. plicatilis*, *Shellwienella crenistria*, etc.

Dinantian of Central China.

Nanking Hills. Though probably of rather wide distribution, the Dinantian of central China is best known from the Nanking Hills, where it was originally described by von Richthofen, though he at first referred these beds to the Devonian. The type locality is

Ch'i-Hsia-Shan, (Hsihsia-Shan of v. Richthofen) a hill on the south side of the Yangtze, northeast of Nanking (Fig. 171). From this locality von Richthofen named it the Hsihsiashan limestone (now called Ch'ihsiashan or Ch'ihsia limestone). The same formation is again shown in the Ch'uan-Shan (Tshu-Shan of von Richthofen,

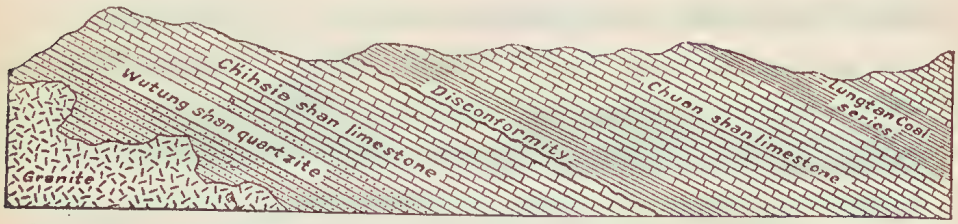

Fig. 172. Generalized section of Ch'uan-Shan, east of Nanking, (Nanking Hills), showing the intruded basal granite (Jurassic) into the Wutung-shan quartzite and the relationships of the Chihsiashan (Dinantian) and Chuan-shan (Permo-Carboniferous or Permian) limestones. (Modified after von Richthofen).

Fig. 172), in the Chin-Lung-Shan, the Mu-Fu-Shan and elsewhere. It is a gray fossiliferous, cherty, limestone, in which the fossils are chiefly compound corals, the species *Syringopora ramulosa* Gold. (Fig. 173), *Fistulipora minor* McCoy (Fig. 174), *Michelinia*, and *Siphonodendron* prodominating. A characteristic simple coral of this formation is *Amplexus spinosus* var. *sinensis* Grabau (Fig. 175). The age of the formation is late Viséen, and its thickness averages from 30 to 40 meters. In all these sections, the Ch'ihsiashan limestone rests with apparent conformity upon reddish to white compact quartzite, the Wut'ungshan quartzite, 600 meters in maximum thickness. The age of the Wut'ungshan quartzite has been thought to be Devonian, but is more probably Dinantian, representing the beginning of continental sedimentation in later Dinantian time, before the transgressing sea reached this district. In some sections the quartzite is partly cut out by intrusive granite (Fig. 172).

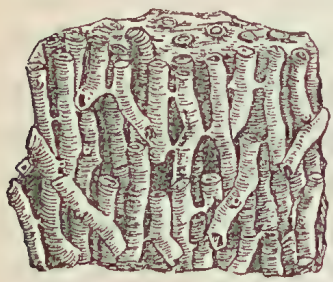

Fig. 173.
Syringopora ramulosa E. and H.

The Ch'ihsiashan limestone appears to be disconformably succeeded by late Carboniferous or Permo-Carboniferous strata, there being at present no representative of the Taiyuan series known in this section.

THE YANGTZE GORGES. Near the Szechuan-Hupeh border, von Richthofen found black limestones of great thickness (Wutai ?) especially characterized by corals. The following species, identified by Frech (5) were obtained between the Mitau and Lukan gorges: *Zaphrentis delanoui* E. & H.; *Z. guerangeri* E. & H. (Fig. 176); *Michelinia favosa* Goldf. (small-celled form) (Fig. 177); cf. *Battersbya* sp. These beds are similar to those found far to the east, in the Nanking Hills.

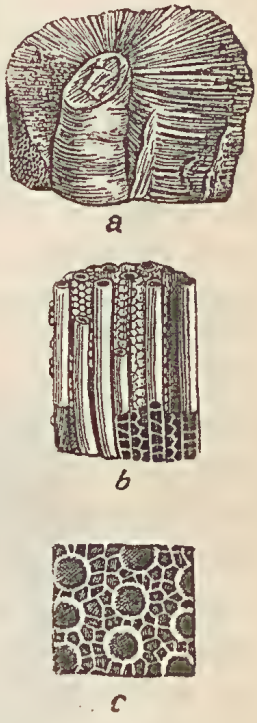

Fig. 174.

Fistulipora minor McCoy; *a*, an old colony surrounding a foreign body; *b*, a small portion enlarged four times, showing large tubes and intermediate tubules; *c*, transverse section × 12.

TSINGLING GEOSYNCLINE. The Carboniferous rocks of the Tsingling geosyncline are still too little known to enable us to state with certainty the nature and extent of the Dinantian series in that region. That it occurs there is probably not to be doubted, indeed there is good reason for believing that both the Viséen and the Taiyuan series are present, since they occur in the westward extension of this geosyncline in Kansu. In the north-eastern part of the geosyncline, the series is probably included in the Wutai limestone of Willis and Blackwelder, or it may be represented by the upper Sintan shale series, which underlies that limestone, and from which Bryozoa of Dinantian age have been obtained, along with brachiopods suggestive of an earlier horizon. (Girty 10).

West Kansu. On the banks of the Bardoun River (Patung-ho), a tributary of the Edsin-gol, at a locality a little above the entrance of the Tchoukchtja (long. 99° E., lat. 39° N.), Lower Carboniferous limestones were found by M. G. Potanin, and the fossils listed by Venukoff (Wenjukow) (48). Fossils of the same age have also been found by von Loczy at Santachien, farther to the east. At Bardoun the beds enclose the following species: Foraminifera: *Endothyra bowmanni* Phill. (Figs. 163 d, e), *E. globulus* Eich., *E. crassa* Brady, *Bradyina potanini* Wen., **Fusulinella struvii* Möll. Brachiopoda: **Productus giganteus* Mart., (Fig. 149), *P. punctatus* Mart., *Schellwienella crenistria* (Phill.), *Spiriferina octoplicata* Sow., *Martinia glabra* (Mart.), *Dielasma sacculus* (Mart.), *Terebratula hastata* Sow., *Athyris globularis* Phill. Ostracoda: *Leperditia okeni* Münst., *Bairdia curta* McCoy, *B. plebeia* Reuss., *B. brevis* J. and K., *B. ampla* Reuss, *B. amputata* J. and K., *B. subelongata* J. and K., *B. hisingeri* Münst., *Bythocypris cometa?* J. and K., *B. bilobata* Münst. Corals (etc.): *Chætetes radians* Eich., *Syringopora mongolica* Wenj.

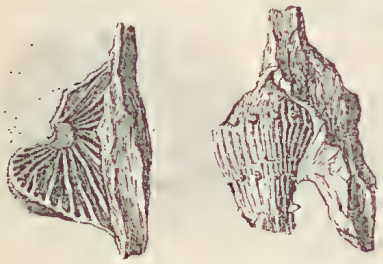

Fig. 175.

Amplexus spinosus var. *sinensis* Grabau, Top and side views of specimen attached to rock.

Fig. 176.

Zaphrentis gucrangeri E. & H. Calicinal view.

The species marked with an asterisk have also been obtained by von Loczy from Santachien, where, in addition, the following were also found. *Chonetes* cf. *papilionaceus* Phill. (Fig. 167), *Euphemus* cf. *urii* (Flem.), *Fusulina cylindrica* Fisch., *Spirillina irregularis* Möll., *Lingulina szechenyii* Lörenthy, *Tetrataxis conica* Ehrenb.,

Climacammina bradyi Möll. The Taiyuan series of Kansu will be considered in the next section.

The extent of the Visêen invasion of the Chinese basin, and the connections with other water bodies in Asia, are indicated upon the palæogeographic map (Fig. 148 p. 220).

THE TAIYUAN SERIES OF NORTH CHINA.

(Sections Fig. 178).

Throughout north China, the Carboniferous is divisible, as we have seen, into (1.) the TAIYUAN series, and (2.) the SHANSI series.

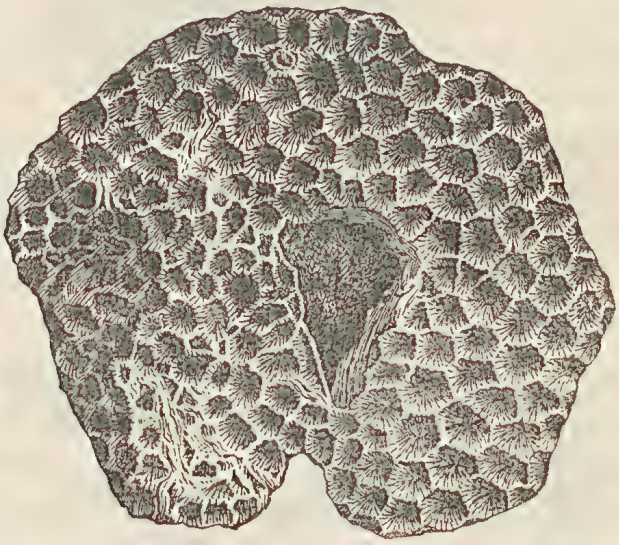

Fig. 177. *Michelinia favosa* Goldf. Top view, slightly reduced.

The age of the former is here regarded as late Lower Carboniferous; that of the latter as Permo-Carboniferous. The Taiyuan series generally rests disconformably upon the eroded Middle Ordovician or older rocks, while the Shansi series rests disconformably upon various members of the Taiyuan series. The sections represent these deposits in the several provinces.

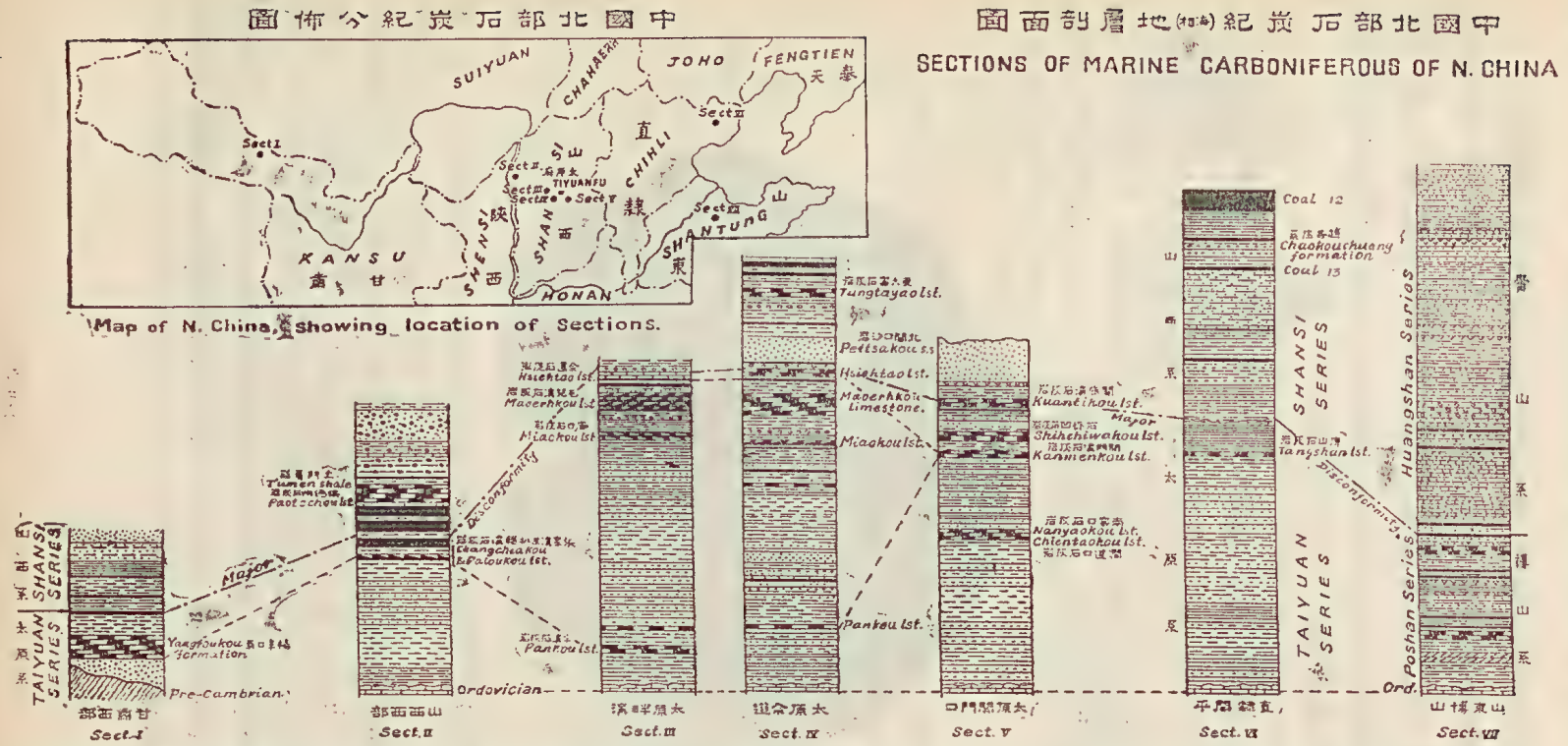

Fig. 178. Columnar section of the Taiyuan and Shansi formations of northern China, showing their relative thicknesses and character, and the main lines of disconformity. The locations of the sections are shown upon the small map. Sect. 1, Central Kansu, 1400 li (800 Km.) west of Taiyuan-Fu; Sect. II, West Shansi (near Paotechou), 280 li (160 Km.) west of Taiyuan-Fu; Sec. III, Pankou, Shansi, 55 li (30 Km). west of Taiyuan-Fu; Sect. IV, Hsiehtao, Shansi, 30 li (17 Km.) west of Taiyuan-Fu; Sec. V, Kuan-Men-Kou, Shansi, 15 li (8.6 Km.) east of Taiyuan; Sect. VI, Kaiping coal basin, Chihli, 840 li (480 Km.) east of Taiyuan-Fu; Sect. VII, Poshan, Shantung, 700 li (400 Km.) south-east of Taiyuan-Fu. (I, Loczy and Hsieh; II, C. C. Wang; III-V, Norin; VI, Mathieu, Barbour and Grabau; VII, T'an.)

KANSU (Fig. 178 i). Along the northern slope of the Nanshan range, shales and limestones (YANGFOUKOU FORMATION) rest unconformably with a basal sandstone, upon the Nanshan series (Pre-Cambrian), and contain a rich fauna representing the lower horizon of the Taiyuan series of north China. Characteristic fossils are: *Spirifer bisulcatus* var. *kansuensis*, *Spirifer pankouensis*, *Enteletes lamarckii* (Fig. 153), and *Phillipsia kansuensis* (Fig. 154). There are also many species of *Productus*, and other fossils. Then follow the principal coal seams of the region, and higher shales and sandstones of Permo-Carboniferous age. Apparently the Taiyuan series here overlaps the Viséen of Bardoun and Santachien.

WEST SHANSI (Fig. 178 ii). Here the Ordovician limestone is followed by 48.5 meters of shales and sandstones, and these by the CHANGCHIAKOU and PALOUKOU LIMESTONES. These contain essentially the fauna found in west Kansu, with some additional species. The four typical species of the Kansu section also occur here, indicating the same geological horizon. This series is followed by the main coal seams of the region (17 meters thick). Above this lie Permo-Carboniferous beds, beginning with the PAOTECHOU LIMESTONE followed by the T'UMEN SHALE, both very fossiliferous. There is thus a great hiatus between the lower and upper limestones of this section.

CENTRAL SHANSI (Figs. 178 iii-v). Both west and east of Taiyuanfu, the Taiyuan series is typically exposed. There are several distinct limestone zones, each characterized by distinctive fossils. These are from above downwards.

8 Kuantikou limestone	4 Miaokou limestone
7 Shihchiwakou limestone	3 Pankou limestone
6 Hsiehtao limestone	2 Nanyaokou limestone
5 Maoerhkou limestone	1 Chientaokou limestone

Nos. 1 and 2. and 7 and 8 are found only east of Taiyuanfu (Fig. 178 v) where nos. 4-6 are cut out by a disconformity. No. 1

is rich in *Fusulina*, containing few other fossils. No. 3 is the lowest limestone of west Shansi and of Kansu containing the same fossils. Nos. 4,5 and 6 contain many brachiopods: (*Chonetes nyströmi* (Fig. 156), *Productus taiyuanfuensis*, *P. punctatus*, *Spirifer bisulcatus* (Fig. 152), etc.); pelecypods: (*Aviculopecten*, *Entolium*, etc.), and gastropods. West of Taiyuanfu, these beds are followed directly by the Permo-Carboniferous series with one limestone (TUNGTAYAO LIMESTONE). East of Taiyuanfu, however, beds 7 and 8 appear below the major disconformity. These are also rich in fossils.

CHIHLI (Fig. 178 vi). In the Kaiping coal basin, the Taiyuan series is represented by 85 meters of continental shales and sandstones, capped by the TANGSHAN LIMESTONE which abounds in corals (*Lithostrotion kaipingense* (Fig. 161), *Alveolites tangshanense*, etc.) and also contains *Spirifer bisulcatus*, the index fossil of the Taiyuan series of north China. Above this follow shales and sandstones with corals, etc., with one fossiliferous zone (CHAOKOUCHUANG FORMATION) with a Permo-Carboniferous fauna.

SHANTUNG (Fig. 178 vii). In the Poshan and other coal fields of Shantung, the Taiyuan series is represented by about 100 meters of shales and sandstones with some coals, and two limestones (here called the POSHAN SERIES). The characteristic Taiyuan fauna with *Spirifer bisulcatus*, and corals (*Lophophyllum*, *Lopholasma*, etc.) is found especially in the upper limestone. The series is disconformably succeeded by the HUNGSHAN SERIES (Permo-Carboniferous), with many coal beds, but no marine fossils. The extent of the invasion, at the end of Taiyuan time, is shown on the palæogeographic map (Fig. 221).

The relationship of the Taiyuan series of Shansi to the underlying Ordovician limestones is shown in Fig. 179, after Willis and Blackwelder.

The Continental Beds and Coals of the Taiyuan Series.

In the TAIYUAN SERIES of north China, the continental beds are more extensively developed than are the marine members. These continental beds are red shales and sandstones near the base, often with beds of fire-clay, and sandstones and shales higher up, the latter plant-bearing at certain horizons, (*Cordaites*, *Lepidodendron*, *Neuropteris* cf. *schlehani* etc.). In central Shansi, where the series is about 125 meters thick, it encloses a number of bituminous coal seams, some of them very extensively worked. One of these lies just below the Kuantikou limestone. Besides this, there are many important anthracite coals, all of which occur in the Taiyuan Series. Out of twelve coal seams observed by Mr. Norin in the Taiyuan Series, nine are succeeded by limestones, and only three by quartz sandstones. Those seams which are subjacent to marine limestones, generally have a wider horizontal extension than those succeeded by quartz sandstones. The thickest seams of bituminous coal, occur however, in the SHANSI SERIES.* (Norin 33).

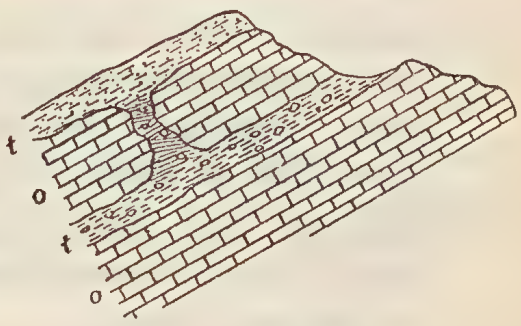

Fig. 179.

Section of the disconformable contact between the basal Taiyuan strata (t,t), and the Ordovician limestone (o,o), in Shansi. (After Willis and Blackwelder.)

In northern Chihli, no workable coal appears to exist in the Taiyuan series, those of the Kaiping basin all belonging to the Shansi series (Permo-Carboniferous) (See further Chapter IX).

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* For further details, see E. Norin. Bull. Geol. Survey China, Vol. IV. p. 52.

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CHAPTER VIII.

THE HIGHER CARBONIFEROUS FORMATIONS.

After the separation of the Dinantian (Mississippian) from the old Carboniferous system, there remains a great series of formations which overlies the Dinantian and underlies the Permian. As long as the Dinantian was called Lower Carboniferous, this higher series was generally spoken of as Upper Carboniferous. The Russian geologists, in whose country the marine facies of these beds is best developed, have devided this supra-Dinantian series into Middle and Upper Carboniferous, with the respective designation of Moscovian and Uralian.

In America this, the chief coal producing system, has been called Carbonic by Dana, and is generally known as Pennsylvanian or Pennsylvanic. This name is however unsatisfactory as it refers primarily to the incomplete continental series in which the coals are found.

The Younger Carboniferous Formations of Europe.

In eastern Europe the higher Carboniferous beds are chiefly marine. The subdivision is as follows:

Marine Divisions of the Younger Carboniferous.

C. Uralian Series. (As developed in the Urals and Timan).

3. Limestones etc., with *Schwagerina princeps* (Fig. 205) and *Fusulina verneuili* (Schwagerian)—contains also: *Griffithides rœmeri*, *G. gruenewaldti*, *Brachymetopus uralicus*, *Agathiceras uralicum*, *Conocardium uralicum*, and many brachiopods, including *Dielasma plica*, *D. mœlleri*, *D. truncatum*, *D.*

itaitubense, Spirifer rectangulus, S. panduriformis, S. lyra, Spiriferina corculum, S. ornata, S. saranæ, S. panderi, Rhynchonella wangenheimi, R. granulum, Pugnax utah, P. keyserlingi, Camarophoria sella, C. pinguis, C. superstes, Notothyris nucleolus, N. warthi, Hemiptychina sublævis, H. triplicata, Hustedia remota, Orthotichia morgani, Rhipidomella pecosi, Derbya grandis, Chonetes variolatus, C. uralicus, Aulosteges uralicus, Productus boliviensis, P. fasciatus, P. inca, P. uralicus, P. tenuistriatus, P. splendens, P. latus, Marginifera involuta, Proboscidella genuina.

2. Clayey and oolithic limestones (Cora Beds), with abundant *Productus cora* (Fig. 180) and with *P. timanicus*. Also contains: *Griffithides scitula, Dielasma bovidens, D. millepunctatum, Hustedia remota, Spirifer musakheilensis* (*-cameratus*), *Spiriferina saranae, Rhynchopora nikitini, Camarophoria crumena, Meekella striatocostata, Chonetes variolatus, Dalmanella juresanensis, Productus semistriatus, P. multistriatus, P. porrectus, P. uralicus, Fusulina verneuili.*

1 b. Coral limestone, with *Petalaxis timanica, Columnaria solida, Syringopora parallela, Omphalotrochus whitneyi, Productus porrectus, Dielasma bovidens, Rhynchopora nikitini, Aviculopecten timanicus*, etc.

1 a. Grayish-red limestones with *Spirifer musakheilensis, Productus semistriatus, P. orientalis, P. lobatus* mut. *russiensis, P. inflatus, P. timanicus, Camarophoria crumena, Derbia regularis* etc.

This lower division of the Uralian in the Urals represents the typical GSCHELLIAN dolomites of the Moscow region or the so-called middle Fusulina limestone or zone of *Spirifer supramosquensis* (Fig. 183). It contains also: *Spiriferina saranae, S. ornata, Spirifer musakheilensis* (*-cameratus*), *Athyris royssi, Retzia grandicosta, R. pseudocardium, Rhynchopora nikitini, Productus boliviensis, P. subpunctatus, P. longispinus, P. parvulus, Chonetes uralicus, C. geinitzi, C. dalmanoides, Camarophoria purdoni, Euomphalus canaliculatus, E. gschellia,* and large *Fusulina,* (*F. longissima*).

B. MOSCOVIAN SERIES (most typical in Moscow region). Also called Lower Fusulina limestone. Zone of *Spirifer mosquensis* (Fig. 184), and small Fusulinas (*F. cylindrica* etc.). Also contains: *Enteletes lamarcki, Meekella eximia, Spirifer fasciger* (sens. strict.) *Spirifer strangwaysi, Sp. okensis, Productus lineatus, Chonetes pseudovariolaris, Archæocidaris rossica, Botrophyllum, Stemmatocrinus, Poteriocrinus, Cromyocrinus,* and *Hydriocrinus.*

A. DINANTIAN—Carboniferous Limestone (Lower Carboniferous).

In the Donetz basin, the Moscovian has a thickness of about 6,000 meters, and rests upon 7,000 meters of Dinantian (Donjetian) limestone, etc. The Moscovian here consists principally of sandstones and shales with numerous coal beds, and some limestones with marine intercalations, and throughout carries the typical Moscovian fauna. The plant remains indicate the Saarbrückian (Westphalian) horizon of the non-marine coal series of west Europe. The Moscovian is succeeded, with apparent conformity, by the Uralian, which is about 5,000 meters thick. This still encloses a considerable number of coal beds in the lower part, where there are also many marine intercala-

tions. These marine beds still contain many Moscovian species, including *Sp. mosquensis* (Fig. 184), but in addition a new form, *Spirifer supramosquensis* (Fig. 183), has appeared. The flora also retains some of the older forms, though *Lepidodendron* has disappeared. The new element of the flora which appears is that of the lower

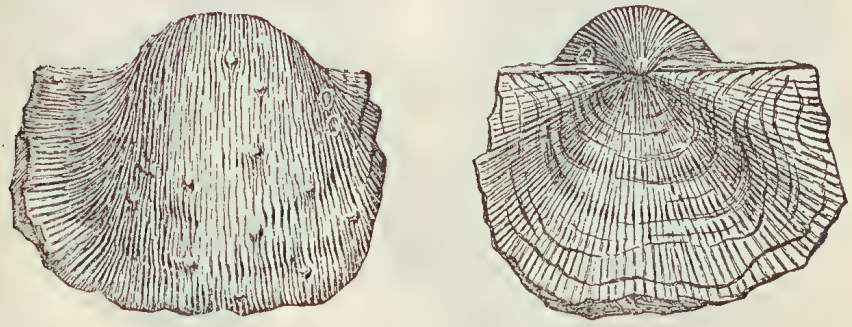

Fig. 180. *Productus cora* d'Orb.

Ottweilian of west Europe. The next division contains only a few coal beds, while *Spirifer mosquensis* and its associates are gradually disappearing, and *Productus cora* (Fig. 180) becomes the dominant type. The highest division of the Uralian is formed by arkoses, shales and limestones. The mosquensis types have disappeared and Upper Carboniferous species (*Sp. cameratus* (lower part), *Productus præpermicus*, *P. artiensis*, *P. alternatus*, *P. lineatus*, *P. cora* (Fig. 180), *P. tenuistriatus*, *Enteletes carnicus*, *Meekella striatocostata*, *Rhipidomella pecosi*, *Rhynchopora nikitini* (Fig. 181), etc. and *Schwagerina* have taken their place. With these occur plant beds which enclose the remains of the upper *Ottweilian* or Stephanian flora. The series is succeeded by *Artinskian* and higher Permian beds.

Fig. 181.
Rhynchopora nikitini Tschern. × 1½.

In western Europe the continental, generally coal-bearing, beds of the Carbonic allow of the following subdivision (in descending order).

Non-Marine Divisions of the Younger Carboniferous.

Ottweilian; characterized by the strong development of *Pecopterids* and by *Callipteridium*, broad-leaved *Sphenophyllum*, *Annularia* and *Odontopteris;* and by the suppression of *Lepidoden-*

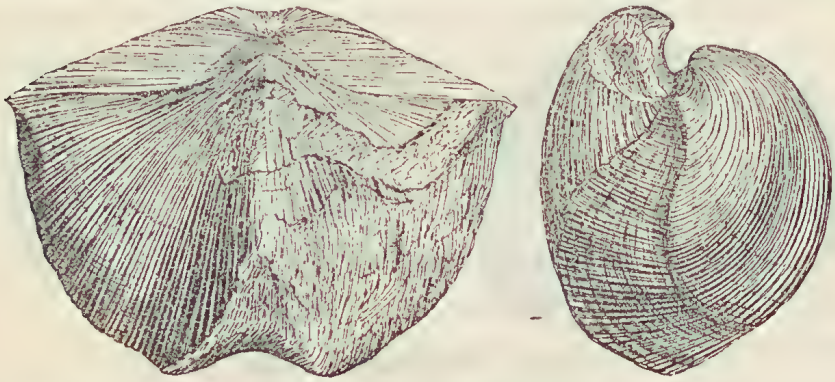

Fig. 182. *Spirifer marcoui.*

drids, of *Sphenopteris* (*sens. strict.*) and *Lonchopteris*. The more important species are: *Neuropteris cordato-ovata* Weiss. *Pecopteris arborescens* (Fig. 185), *Callipteridium pteridium* (Fig. 186), *Annularia stellata* (Fig. 187), *Sphenophyllum verticillatum* (Fig. 188).

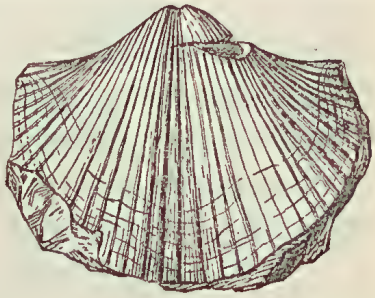

Fig. 183.
Spirifer supramosquensis Nik.

Saarbrückian (upper part of Westphalian); characterized by the first appearance of *Pecopteris*, *Odontopteris*, *Alethopteris*, *Dictyopteris*, *Lonchopteris* (Fig. 189), *Mariopteris* (Fig. 190), and *Palmatopteris*, while broad-leaved *Sphenopteris* (Fig. 191) are abundant. Abundant also are *Sigillaria elongata* (Fig. 192), *S. elegans*, etc. *Annularia radiata* (Fig. 193) (in lower), *A. stellata* (Fig. 187) (in

upper), *Calamites ramosus*, *C. suckowi* (Fig. 194), etc. *Eucalamites* and *Calamitina* also occur, while the older forms have entirely disappeared.

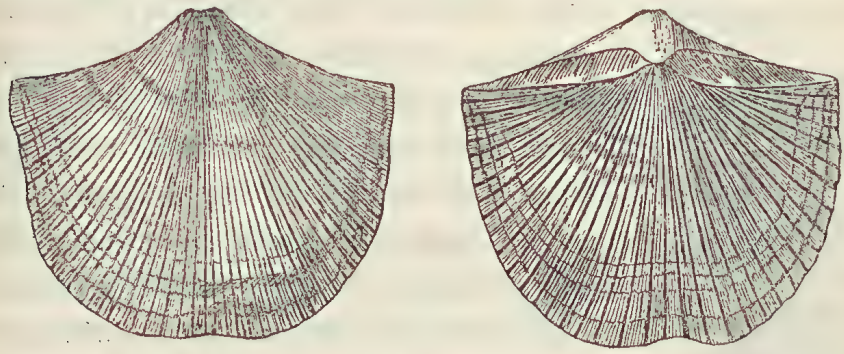

Fig. 184. *Spirifer mosquensis* Fisch. de Waldh.

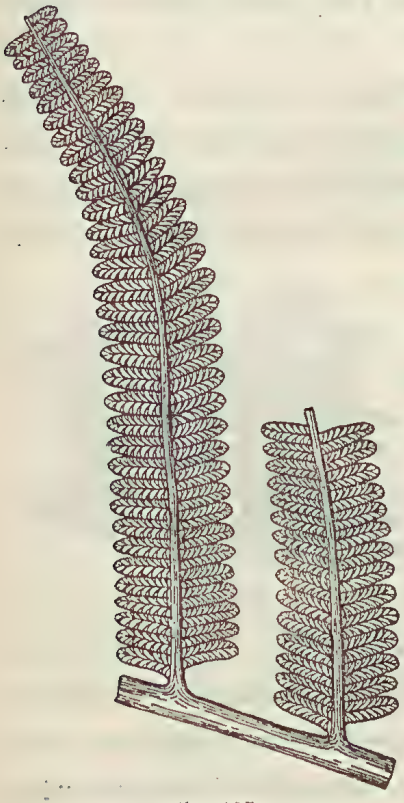

Fig. 185.
Pecopteris arborescens (Schloth.)

SUDETIAN or WALDENBURGIAN (Lower Westphalian); especially characterized by *Lepidodendron veltheimianum* (Fig. 146) (lower), *L. volkmannianum* (Fig. 195), (upper), *Sphenopteris elegans* (Fig. 196), *S. divaricata* (Fig. 197), *S. shimperi*, and *S. distans*. Appearing for the first time are *Sphenophyllum* of the *S. tenerrimum* type (Fig. 198), and longitudinally striped Sigillarias (*Eosigillaria antecedens*) (Fig. 199). Other typical species are: *Neuropteris schlehani* (Fig. 200), *Alloiopteris quercifolia* (Fig. 201), and *Adiantites oblongifolius* (Fig. 202).

Besides these, most of the older Dinantian forms still continue, the change in flora being a gradual one.

In the east European region, the Moscovian Sea was a transgressing one, deposits of this age resting directly upon the Devonian, between the Onega and the Pinega in northern Russia. A similar transgression of the sea affected Bear Island at a somewhat later stage, for there the Gschellian, with *Spirifer supramosquensis* (Fig. 183) and *Athyris ambigua* rests disconformably upon the Upper Devonian continental beds. On Spitzbergen the Moscovian appears to be absent, the Uralian with *Productus lineatus*, *P. timanicus*, *P. boliviensis*, *Spirifer cameratus*, etc., resting disconformably upon continental Dinantian beds with *Lepidodendron veltheimianum* (Fig. 146), *Bornia radiata* etc.

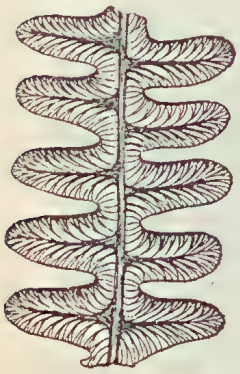

Fig. 186.
Callipteridium pteridium Schl.

Throughout western Europe the post-Dinantian Carboniferous beds are chiefly non-marine, with few marine intercalations in the lower part, as already noted in the preceding chapter. In the eastern Alps, however, marine beds of Uralian age, rest unconformably upon either the ancient crystallines, or on folded older Palæozoics, including the Dinantian. Thus there is indicated in that region, a period of tectonic disturbance during Moscovian time. The lowest of these Uralian beds (Auernigg beds) carry *Spirifer supra-mosquensis* (Fig. 183), *Fusulinas*, *Griffithides scitula*, gastropods and *Productus lineatus*, and other brachiopods. They, therefore, represent the Gschellian or a somewhat younger horizon. Above these beds follow limestones with *Schwagerina princeps* (Fig. 215) and *Fusulina*, and upon these lie

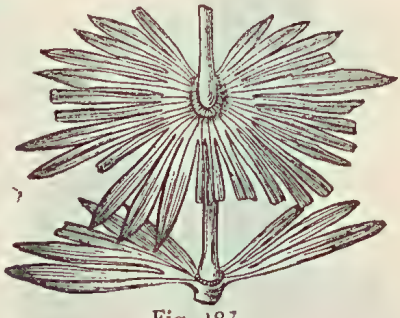

Fig. 187.
Annularia stellata Schl.

limestones of Permian age. The Schwagerina beds of the Uralian are again found transgressive on continental older sediments in southern Dalmatia (Budua). Earlier beds, however, with *Sp. supramosquensis* (Fig. 183) are found to be transgressive in Balia Maden, in Mysia, Asia Minor.

Fig 188.
Sphenophyllum verticillatum Germ.

Far to the south-east in the valley of the Nasb, in Arabia Petræa, both Dinantian with *Rhipidomella michelini* and *Schellwienella crenistria*, and Moscovian with *Productus semireticulatus*, *Spirifer convolutus*, *S. mosquensis*, *Enteletes ægyptiacus*, etc. have been found. Farther west, in the Sahara (Tasili Mountains), beds with *Spirifer rectangulus* and *Productus semireticulatus*, supposed to represent the Moscovian, are succeeded by Uralian beds with *Productus cora*, *P. lineatus*, *P. gallatinensis*, *P. inflata*, *Camarophoria purdoni*, etc. The Moscovian age is also suggested by some fossils found in the extreme south of Morocco (Draa Valley).

In upper Egypt, the Nubian sandstone of Wadi Araba contains *Lepidodendron* and *Sigillaria*, as well as beds with a marine Upper Carboniferous fauna. Some of the corresponding beds in Arabia and Syria may belong here.

The Younger Carboniferous Formations of Asia.

Turning now to Asia, we find there Moscovian beds very sparingly developed. They have been observed by von Toll (71) in the delta of the Lena River in the extreme north of Siberia. In central Asia a number of occurrences have been reported but it is not always certain to what extent these are authentic. Upper Carboniferous beds seem, however, to be much more widespread, especially the horizon of *Schwagerina princeps* (Fig. 215), which is placed in the

Upper Uralian by the Russian geologists but has been recorded as Lower Permian by Frech and others. In some sections, the Lower Uralian or Gschellian, seems to have a wide distribution.

Fig. 189.
Lonchopteris rugosa Brgt.

Asia Minor. Younger Carboniferous strata are much less widely distributed in Asia Minor than are the Dinantian. Indeed, Middle Carboniferous beds appear to be wholly unknown at present, while Upper Carboniferous beds occur in a number of localities in the western part of Asia Minor. In the Taurus there appears to be a hiatus extending from the top of the Dinantian to the base of the Upper Cretaceous (Frech). Elsewhere too, in eastern Asia Minor the Upper Carboniferous appears to be absent. Indeed, it may be questioned in how far the beds classed as Upper Carboniferous in western Asia Minor really belong there, for according to Dyhrenfurth, the Fusulina limestones of Asia Minor belong mostly to the Permian. In Balia-Maden, in extreme western Asia Minor (Mysia) and in a few other localities, a complete succession from Upper Carboniferous into Lower Permian appears to exist. The coal beds of Eregli and Amasra on the southern Black Sea coast are enclosed in a wholly non-marine series of deposits representing

Fig. 190. *Mariopteris sauveuri* Brgt.

upper Saarbrückian, Westphalian and Sudetian horizons, and comprising sandstones, conglomerates, gray shales, clays and numerous coal beds.

Fig. 191. *Sphenopteris bæumleri* Andreæ, with enlarged pinnule.

Syria and Arabia. Very little is known of the occurrence of Carboniferous strata younger than Dinantian in the region bordering the eastern Mediterranean. The Egyptian deposits of Wadi-Araba, above referred to, may extend across the Red Sea, but positive evidence of this seems to be lacking. There is, however, in western Hedjaz some evidence that the middle portion of the Nubian sandstones may be of Carboniferous age, especially that occuring in the region of the old Medianitic city Maghair Schu'aib and on Wadi-Afal (Blanckenhorn 2).

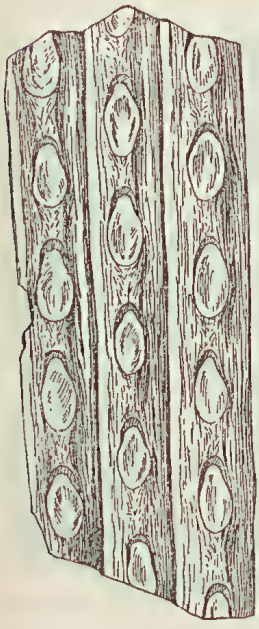

Fig. 192. *Sigillaria elongata* Brgt. Stem fragment.

I have represented on the palæogeographic map (Fig. 221) the connection between the Mediterranean and central Asiatic waters in Moscovian time, but it must be confessed that this is extremely hypothetical, and it is quite possible that all this region was dry land during the middle period of the Carboniferous. So far as our present knowledge goes, no Middle, or even Upper Carboniferous beds occur over the greater part of northern Arabia, though of course their occurrence there is not excluded.

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Persia. Middle and Upper Carboniferous beds are known from only a few localities in Persia, the distribution of these formations being much less extensive than that of the Dinantian. From the Mendjil district of the central Elburz mountains a dark limestone with *Spirifer mosquensis*, *S. glaber* and *Productus striatus* has been obtained, indicating the presence there of Middle Carboniferous. Similar beds continue eastward for a considerable distance. Upper Carboniferous and Lower Permian beds are more widely distributed than are those of Middle Carboniferous age. The mountains south and south-west of Djulfa, on the Araxes River, which forms the boundary line between Russia, Armenia and Persia, contain limestone with *Schwagerina* and *Lithostrotion*, forming beds up to two feet in thickness. These represent the deposits of the late Upper Carboniferous or Permo-Carboniferous transgression. Somewhat older beds with *Productus gruenewaldti* Krot., *Pr. fasciatus* Kut., *Pr. gratiosus* Waag., *Streptorhynchus pelargonatus* Schloth., *Reticularia lineata* Mart., and *Spirifer ornatus* Waag. occur southeast of Taheran in limestones which include subordinate beds of white and red quartzite. At Emaret

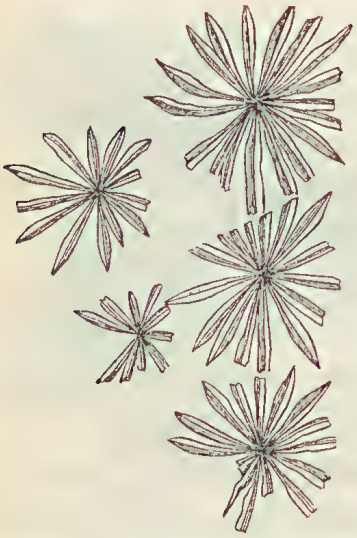


Fig. 193.
Annularia radiata Brgt.

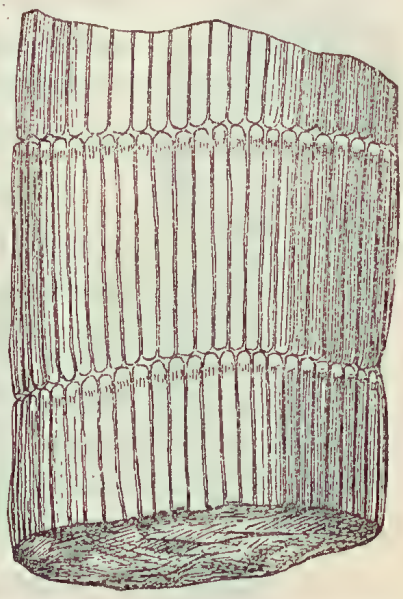


Fig. 194.
Calamites suckowi Brgt. Internal filling of stem, reduced.

too, Upper Carboniferous beds underlie the Jurassic sediments, as is indicated by the presence, at the foot of the mountains, of dark gray limestones with a *Reticularia* closely related to *R. indica* Waag. and *R. waageni* Loczy.

Fig. 195.
Lepidodendron volkmannianum Stbg. fragment, of cast of stem.

TURKESTAN. The Carboniferous of Turkestan is still imperfectly known, this being especially the case for the Middle Carboniferous which seems to have a very limited distribution. In eastern Ferghana dark clays and limestones with some sandstones and conglomerates, represent the higher Carboniferous, these resting in most cases disconformably upon the Dinantian. Upper Carboniferous beds, together with those of Permo-Carboniferous and Permian age, are well represented in the Darwas Mountains of eastern Bokhara. They consist of great limestones especially characterized by *Fusulina*, and rest unconformably upon older rocks, this region having apparently been an island in Dinantian and Devonian times. The Upper Palæozoic beds of Darwas are divisible into two series, the lower of which represents late Carboniferous, and the higher Permian. The Carboniferous beds consist mainly of light gray, occasionally dark Fusulina limestone of considerable thickness. In comparison with the numerous Fusulinas which are often rock-forming, the other fossils occupy a subordinate position. The following species have been found here by Edelstein, this list with the exception of the Fusulinas being only a partial one. The Fusulinas have been described by Dyhrenfurth (17), while the remainder of the fauna was studied by Tschernyschew.

Fig. 196.
Sphenopteris elegans Brgt.

Partial list of the Upper Carboniferous Fossils of Safed-Daron, Darwas, south-east Bokhara.

FORAMINIFERA: *Fusulina contracta* Schellw., *F. vulgaris* Schellw., var. *globosa* Schellw., var. *fusiformis* Schellw., var. *exigua* Schellw., *F. kraffti* Schellw. BRACHIOPODA: *Dielasma itaitubense* Derby, *D. darvasicum* Tschern., *D. juresanense* Tschern., *D. truncatum* Waag., *Dielasmina edelsteini* Tschern., *Hemiptychina orientalis* Tschern., *H. bukharica* Tschern. *H. dieneri* Gemm., *Aulacothyris uralica* Krot., *A. darvasica* Tschern., *Rhynchonella edelsteini* Tschern., *Notothyris nucleolus* Kut., *N. bukharica* Tschern., *Keyserlingina darvasica* Tschern., *Uncinulus theobaldi* Waag., *U. jabiensis* Waag., *U. arthaberi* Tschern., *Camarophoria sella* Kut., *C. solitaria* Gem., *Spiriferina darvasica* Tschern., *S. holzapfeli* Tschern., *Spirifer lyræformis* Tschern., *S. fritschi* Schellw., *S.* sp. cf. *trautscholdi* Stuck., *Martinia elegans* Diener, *M. uralica* var. *longa* Tschern., *M. incerta* Tschern., *M. semiplana* Waag., *M. corculum* Kut., *M. simensis* Tschern., *Reticularia lineata* Mart., *R. rostrata* Kut., *R.*

Fig. 197. *Sphenopteris divaricata* Goepp; stem with pinna.

(*Squamularia*) *dieneri* Gemm., *Enteletes carniolicus* Schellw., *E. tschernyschewi* Diener, *Aulosteges tibeticus* Diener, *Productus cora* d'Orb., *P. multistriatus* Meek, var., *P. juresanensis* Tschern., *P. darvasicus* Tschern., *P. fasciatus* Kut., *Proboscidella darvasica* Tschern., *Marginifera carniolica* Schellw., *M. involuta* Tschern. MOLLUSCA: *Bellerophon* sp., *Conocardium* sp., *Aviculopecten elegantulus* Stuck. (Tschern. 73).

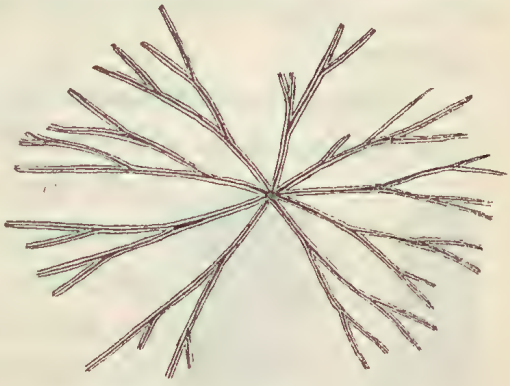


Fig. 198.

Sphenophyllum tenerrimum v. Ett. × 2.

So far as the preceding list permits us to judge, there appears to be a remarkable mixture of forms belonging in part to the early Upper Carboniferous (stage of *Spirifer supramosquensis*), the Upper Carboniferous (*Schwagerina* stage) and the Lower Permian or Permo-Carboniferous (Artinskian). In general the fauna is most nearly related to that of the Schwagerina limestone of the Urals and Timan, though strangely enough no *Schwagerina* have been found in the Darwas deposits.

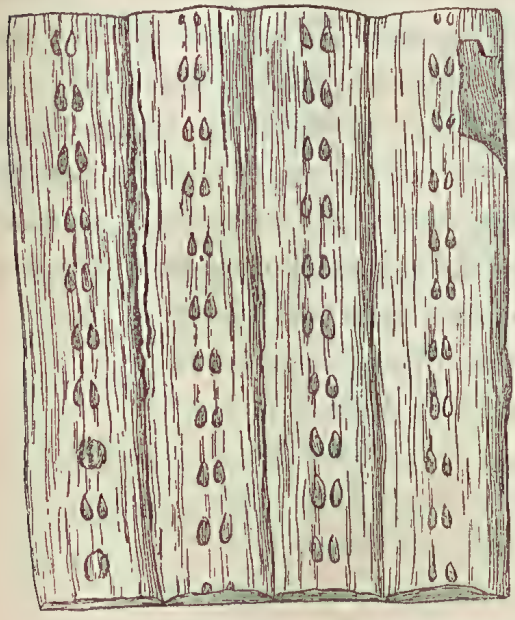


Fig. 199.

Sigillaria antecedens Stur. Compressed stem fragment.

Moscovian beds have been reported from the wes-

tern Kwenlun and Upper Carboniferous has also been found, this being represented on the southern slopes of the Tekeliktagh, in the Kwenlun, by white oölitic limestones with *Productus longispinus* and *Martinia*. A higher horizon representing Permo- Carboniferous, is also found there.

THE TIAN-SHAN RANGES OF WESTERN SINKIANG PROVINCE. On the southern slopes of the Tian-shan mountains, where the foothills rise from the desert sands on the northern border of the Taklamakan, we meet with a succession of marine deposits, on the whole disturbed and fragmentary, but indicating wide distribution of the Lower, as well as Upper Carboniferous formations in this region. The district between Kaschgar and Aksu, or approximately between 76° and 80° E. Long. and 40° and 42° N. Lat., has been studied in greatest detail (Gröber 30 and Keidel 40). A section made by Gröber, in the Asghan-Bulak-Tagh, southwest of Aksu (approximately Long. 79° 50′ E., Lat. 40° 50′ N.) shows the following succession, the beds dipping southeast up to 20 degrees and striking in a general north-east south-west direction. The section in descending order is as follows:

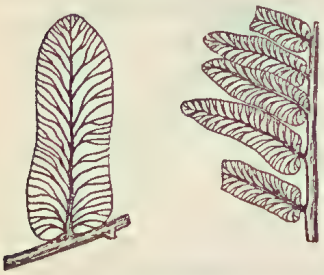


Fig. 200.

Neuropteris schlehani Stur. fragment, and pinnule, × 2.

IV. Late Middle or early Upper Carboniferous.

7. Lava, followed by red marls and clays passing underneath the loess. 5 meters
6. Tuffs, tuffaceous sandstones, red marls and clays, the former predominating in the lower, the latter in the upper part. About..... 200 meters
5. Lava ..... 10 meters
4. Tuffs ..... 15 meters

3. Dolerite lava with prismatic jointing, and including two layers of tuffs. .... 15 meters

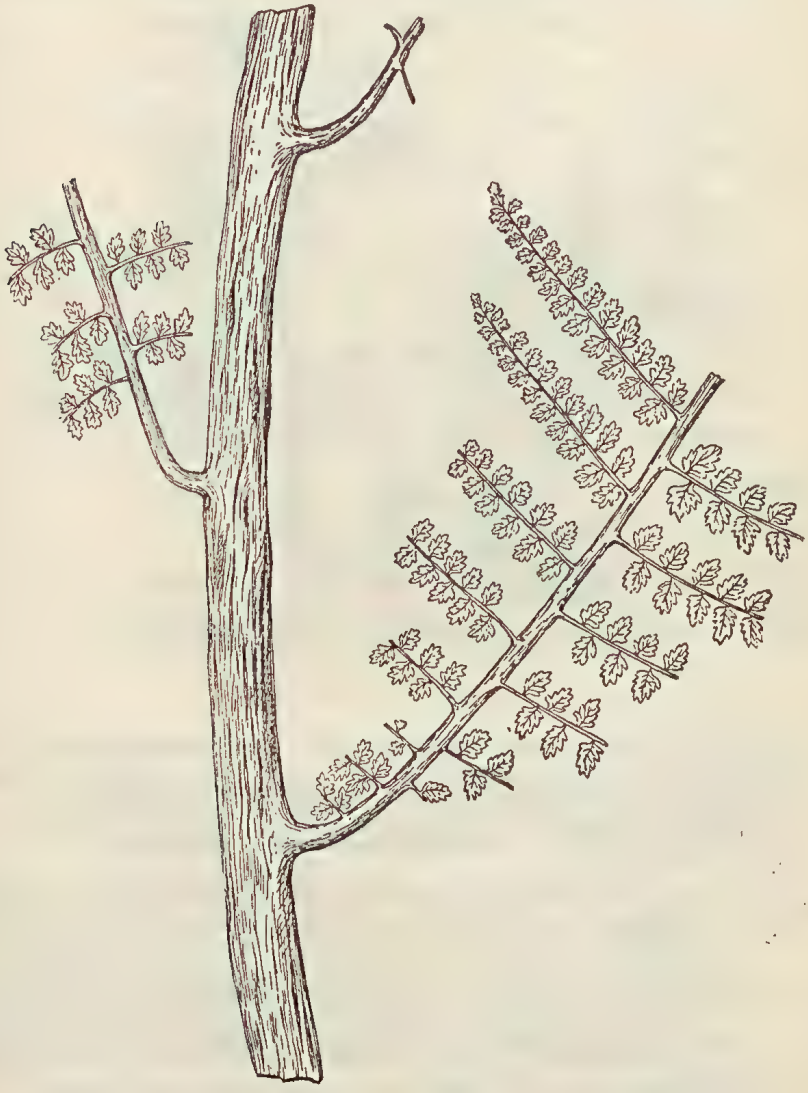


Fig. 201. *Alloiopteris quercifolia* (Goepp.), somewhat reduced.

2. Red and white soft clays, white sandstones and red nodular clays. 150 meters
1. Thin-bedded limestone with subordinate marl..... 5 meters (?)

III. Middle Carboniferous (?) limestones.

4. Coral limestone..... 4 meters

3. Light gray limestone..... 8 meters

Fig. 202. *Adiantites oblongifolius* Goepp., two fragments.

Fig. 203. Section of the Tschong-Kssill-tagh and Känkerin-tagh in the southern Tianshan of west Sinkiang. a, Safärbai limestone, siliceous and dolomitic with chert; b, green soft sandstones, marly shales and slates; c, red shales and sandstone; d, red sandstones (a-d, Upper Dinantian); e, Känkerin limestone; e_1, argillaceous limestone; e_2 white granular *Schwagerina* limestone; e_3, black *Schwagerina* limestone; f, grayish-green flyschlike shale; g, green clay shale (e-g, Upper Carboniferous); l, overthrust mass of Upper Carboniferous limestone. (Modified after Gröber).

2. Schwagerina limestone..... 8 meters

1. Fusulina limestone..... 2 meters

II. Middle Carboniferous sandstones and clays.

11.	White hard cross-bedded sandstones	15 meters
10.	Red clay	75 meters
9.	Compact white sandstones somewhat conglomeritic	20 meters
8.	Hard clays with some sandstones	50 meters
7.	Hard white clayey sandstones	30 meters (?)
6.	Green marls	40 meters
5.	Gray yellow-brown micaceous sandstones	20 meters
4.	Thin-bedded sandstones and red clays with gypsum	15 meters
3.	Thin-bedded red nodular clays	10 meters
2.	Limestone	2 to 3 meters
1.	A bed of flint nodules, partly forming conglomerate and partly united into a quartzite	10 to 12 meters.

Disconformity.

I.	Upper Viséen (*Dibunophyllum* zone). Siliceous limestone and subordinate dolomites with much flint in the lower part and large lenses of crystallized calcite	150 meters.

The second section parallel to the first and about 80 kilometers farther to the south-west, shows the relationships depicted in Fig. 203. Rising above the plain of Kalpin, is the long erosion front of Tschong-Kssill-Tagh, which is entirely composed of siliceous limestone with flints. This represents the upper Dinantian, corresponding to the *Dibunophyllum* zone of the Viséen. It is succeeded by Middle Carboniferous sandstones and shales which separate this ridge from the

Känkerin-Tagh, a similar erosion front of moderately dipping strata of limestone representing the Upper Carboniferous. This is in turn overlain by flysch-like shales, upon which rests an overthrust mass of Upper Carboniferous limestone forming the Kiäkining Aigasi. The succession in this section is as follows in descending order:

II. Younger Carboniferous.

7. Red sandstone and green clay shales..... 200 meters (?)
6. Green clay shales..... 600 meters
5. Kalendér beds. Flysch-like green-gray coaly shales..... 300 to 400 meters
4. Känkerin limestone with *Spirifer mosquensis, S. strangwaysi*..... 60 to 70 meters
   - c. Black limestone with *Schwagerina*
   - b. White, partly sugary limestone with *Schwagerina.*
   - a. Clayey limestone

3. to 1. Kuruk-üsüm beds.
3. Red sandstones..... 150 meters
2. Red shales and marls..... ..... 100 to 150 meters
1. Green clay shales, marls and sandstones..... 200 to 300 meters

Probable Hiatus and Disconformity.

I. Lower Carboniferous siliceous limestones and dolomites.

It is evident that at the end of Lower Carboniferous time this region witnessed a retreat of the sea and a period of continental deposition, this forming the Kuruk-üsüm beds 450 to 600 meters in

thickness. Then followed the re-advance of the sea, and the deposition of the Känkerin limestone (4) 60 to 70 meters in thickness. This contains the following fauna. In the lower dark limestone (a): *Productus aculeatus, P. semireticulatus, P. longispinus, P. scabriculus P. punctatus, Spirifer strangwaysi, S. cameratus, Spiriferina* nova species. In the overlying white sugary limestone (b): *Schwagerina, Fusulina, Productus semireticulatus, Spirifer strangwaysi, S. mosquensis, S. glaber, Dielasma sacculus.* There appears to be here a curious commingling of species, for we find *Spirifer cameratus*, a typical Upper Carboniferous fossil, in beds which underlie limestone with *S. mosquensis*, typically belonging to the Middle Carboniferous or Muscovian. With these is associated *Schwagerina*, which is normally an Upper Carboniferous form. It is possible that the identification of the *Spirifers* in question is open to revision, and that these limestones represent Upper Carboniferous, rather than Middle. This consideration gains strength from the fact that throughout this region the second marine transgression fell in Upper rather than in Middle Carboniferous time.

A continuation of the section just described is found on the north-west side of the great Tschul-talasse depression, beginning at the foot of the Kekelik-bel and extending through the Kepening-bel. In this section we have a partial repetition of the beds found on the south side of the Tschul-talasse, the succession being as follows in descending order.

III. Upper Carboniferous

2. Kekelik-bel beds.
   Green clay slates alternating with
   Fusulina limestone beds, the latter
   subordinate in the main ..... 300 meters

1. Musduk limestones..... 400 meters

II. Middle Carboniferous

1. Kepening beds.

Green clay shales, marly shales and sandstones with red clays and conglomerates abundant in the upper part, limestones with *Spirifer mosquensis* in the middle and green gray and blue clays predominating in the lower part.....1300 to 1500 meters

(Probable hiatus and disconformity.)

I. Lower Carboniferous

2. Limestones and sandstones alternating (thickness unknown).

1. Siliceous limestones and dolomites (thickness unknown).

In the upper valley of the Kukurtuk, northwest of Utschturfan (Uch-Turfan) (approximately Long. 78° 59′ Lat. 41° 28′) the Lower Carboniferous limestone is followed disconformably by beds with Upper Carboniferous fossils. These beds have also been found in a number of other localities in this region and frequently they are separated from the underlying Lower Carboniferous limestone by clastic beds including a conglomerate which contains rolled fragments of the corals from the lower horizon. These higher limestones are especially characterized by *Schwagerina princeps*. From these beds Keidel (40) has described the following faunas: *Notothyris nucleolus* Kut. (Fig. 204), *Productus* cf. *gruenewaldti* Krot., *P. uralicus* Tschern. (Fig. 205), *P. inflatus* McChesney, *P. gratiosus* Waag., *P. subcostatus* Waag., *P. aculeatus* Mart., *P. curvirostris* Schellw., *P. pustulatus* Keyserl., *P. cora* d'Orb., *P. lineatus* Waag. (Fig. 206), *P.* cf. *lineatus* Waag., *P. sinensis* Tschern., *P. tenuistria-*

tus Vern., *P. cancriniformis* Tschern. (Fig. 207), *P. mammatus* Keyserl., *P. punctatus* Mart., *P. fasciatus* Kut., *P. elegans* M'Coy, *Proboscidella* cf. *lata* Tschern., *Marginifera pusilla* Schellw., *M. typica* Waag. var. *septentrionalis* Tschern., *M. involuta* Tschern., *M.* cf. *involuta* Tschern., *M. clarkii* Tschern., *Rhipidomella pecosi* Marcou, *Schizophoria resupinata* Mart., *S. supracarbonica* Tschern., *Orthotichia* cf. *morganiana* Derby, *Enteletes kayseri* Waag., (Fig. 208 *a*, *b*), *E. tschernyscheffi* Diener, *E. hemiplicatus* Hall (Fig. 208 *c*, *d*), *E.* cf. *œhlerti* Gemm., *E. merzbacheri* Keidel (Fig. 209), *Spiriferina cristata* Schloth., *Spirifer* cf. *fasciger*

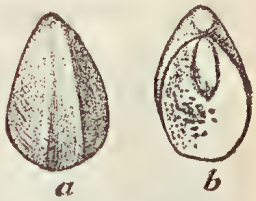


Fig. 204.
Notothyris nucleolus Kutorga.

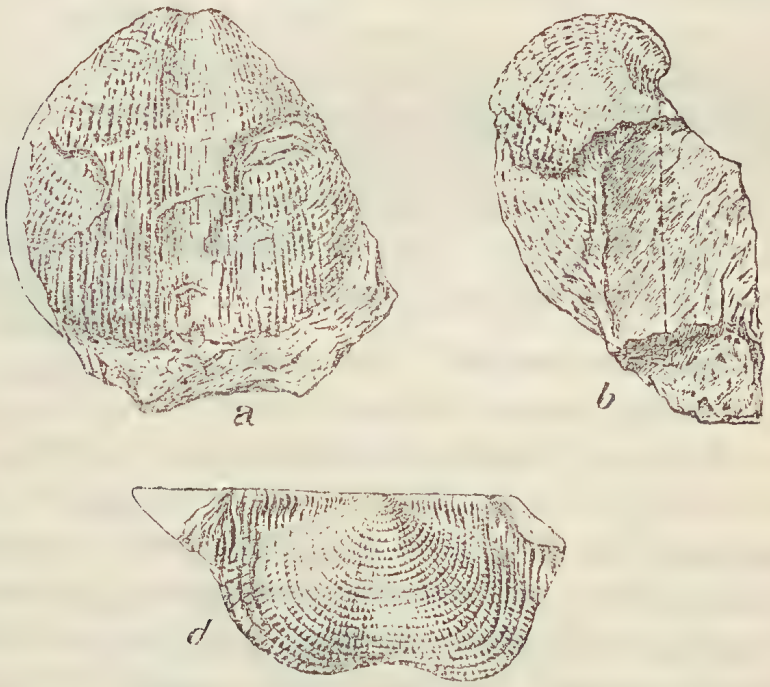


Fig. 205. *Productus uralicus* Tschern. × ⅓.

Keyserl., *S. lyra* Kut. (Fig. 210), *S.* cf. *lyra* Kut., *S. tibetanus* Dien., *S. supramosquensis* Nik. (Fig. 211), *Martinia glabra* Martin,

Martinia corculum Kutorga (Fig. 212), *Reticularia lineata* Mart., *R.* cf. *dieneri* Gemm., *R. rostrata* Kutorga, *Meekella* sp.

Throughout this region there appear to be two periods of folding, one of which belongs to the Lower Carboniferous and the second probably to the Upper Carboniferous. The older folding affected the entire Tian-Shan but the younger one is only recognizable in the narrow zone along the axis of the mountain.

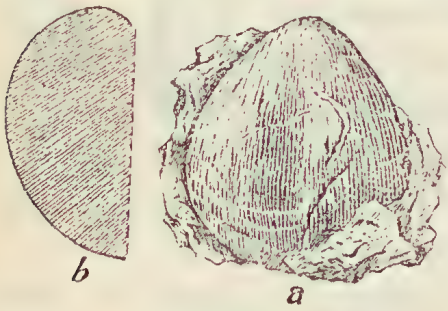


Fig. 206.
Productus lineatus Waag. × $\frac{7}{10}$.

Elsewhere in central Asia, Upper Carboniferous is known from the Kwenlun and the southern Pamir. In the former region Bogdanowitch found the Upper Carboniferous resting transgressively on various formations, including Middle Carboniferous. This, therefore, corresponds in essential characteristics to the conditions seen in the Tian-Shan. Lower Carboniferous appears not to be known in the Kwenlun.

Fig. 207.
Productus cancriniformis Tschern.

Siberia. Over the whole length of Siberia, from the Kusnezk basin to the Pacific Ocean no Middle and Upper Carboniferous formations are known, nor have any been found during the recent expedition in Mongolia by the geologists of the Third Asiatic Expedition. Everywhere the Middle and Upper Carboniferous seem to be represented by a hiatus, strata of Permian age lying directly and disconformably upon the Dinantian. There are, however, extensive coal-bearing deposits of continental origin in western Siberia and here belong those of the Kusnezk basin, and those of the Kirghiz Steppes. According to Tschernyschew, coal-bearing deposits of this region were all laid

down before the formation of the Artinskian sediments of the Ural mountains.

HIMALAYAS. No undoubted marine Moscovian is known from the Himalayas, but beds of Uralian age, and Permian strata are well represented. Unfortunately, the Uralian beds have not always been differentiated from those of Permian age, but that they occur is shown by the fossils which have been obtained, and is the general opinion held by the students of these rocks. Tschernyschew is of the opinion that the lower Productus limestone of the Salt Range represents the Gschellian, carrying as it does the characteristic *Spirifer marcoui* of that horizon. As will be shown later, the probability exists that a hiatus of some magnitude separates the lower from the middle Productus limestone, and that the former belongs to the Uralian while the latter, together with the upper Productus limestone, belongs to the Permian.

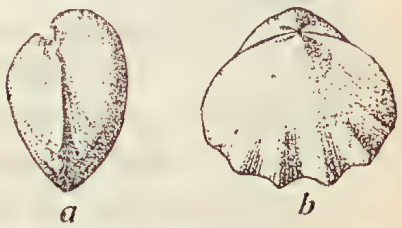


Fig. 208 *a*, *b*.
Enteletes kayseri Waag.

Fig. 208 *c*, *d*.
Enteletes hemiplicatus Hall.

In Kashmir the following succession of formations has been determined by Middlemiss (53a). (In descending order):

PERMIAN

Zewan Series..... ..... 300 feet

PERMO-CARBONIFEROUS

Gangamopteris beds (Talchir).... 800 feet
(Disconformity.)

UPPER-CARBONIFEROUS

Panjal volcanic series

Panjal traps (several thousand feet)

Panjal pyroclastic slates (Agglomeratic states)
(several thousand feet)

MOSCOVIAN?

Fenestella shales .....2000 feet
(Probable disconformity)

DINANTIAN

Syringothyris limestone series.....1000 feet
(Disconformity.)

SILURIAN (or Devonian?)

Muth Quartzite .....3000 feet

The SYRINGOTHYRIS LIMESTONE of Kashmir corresponds to the LIPAK SERIES of Spiti (See p. 235), and consists of gray thin-bedded flaggy limestones with *Syringothyris cuspidata* Mart., *Spirigera subtilita* Hall var. *acuteplicata* Diener, *Productus cora* d'Orb., *P. semireticulatus* Mart., and 10 other, incompletely identified, brachiopods (Diener, IX, 20.). It rests disconformably upon the Muth continental quartzite and is probably terminated by a disconformity, and sometimes followed by the Agglomerate slates and traps of the Panjal volcanic series.

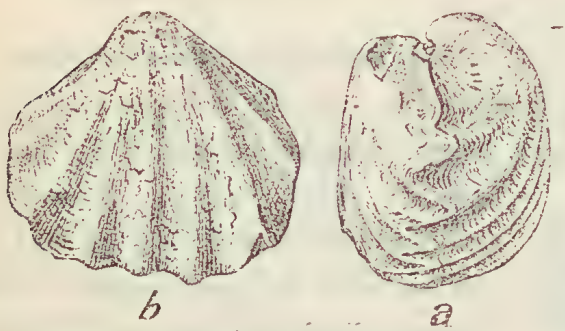
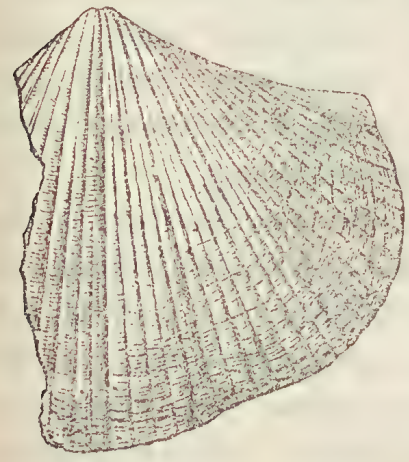


Fig. 209. *Enteletes merzbacheri* Keidel × ⅔.

The FENESTELLA SHALES, which generally intervene between the Syringothyris limestone and the Panjal volcanic series, consist of alternating fossiliferous shales, 100 to 500 feet thick, and unfossiliferous quartzites, which become thicker (up to 600 ft.) upwards as the shales decrease in thickness. The most abundant fossil is a species of *Fenestella*, poorly preserved, but apparently related to, or identical with, *F. plebeia* McCoy. Brachiopods are most numerous, being represented by 30 species, while the pelecypods comprise only 6 species

and trilobites are represented only by an undetermined species of *Phillipsia*. The fauna of these shales is individualistic, showing very little relationship to the faunæ of other known *Anthracolithic* formations. Of 41 species, 20 are restricted to it, and 12 are imperfectly known. The presence of a *Syringothyris* (*S. lydekkeri*), suggests affinities with the Dinantian, but the presence of *Aulosteges* (*A. percostata*), is equally suggestive of Upper Carboniferous age. The Producti (*P. semireticulatus, P. cora, P. scabriculus, P. undatus*), and Spirifers (*S. trigonalis, S.* cf. *triangularis*), found elsewhere, have a wide range and do not determine the age of these beds.

Fig. 210.
Spirifer lyra Kutorga.



a

b

Fig. 211.
Spirifer supramosquensis × 1.

The individualistic character of the fauna shows clearly that it lived during a period when the wide extension of the marine waters, which characterized the Viséen, had come to an end, and more or less isolated water-bodies favored the development of provincial faunas. We have seen that at the close of the deposition of the Taiyuan series, the seas contracted markedly, and that even during the deposition of these beds the Chinese basin was more or less dissociated from the other Asiatic water bodies, so that the Taiyuan fauna has a distinctively provincial aspect. Communication through

the Himalayan channel had certainly ceased, though that through the Nan-shan channel was still maintained. It is possible that this was the period during which the Fenestella shales of Kashmir were formed, and their provincial fauna was developed from Dinantian survivors. Or these shales may belong to a later period of the Moscovian, when the east Asiatic region was unsubmerged (See beyond).

The formation of the PAJAL SERIES of pyroclastics and traps clearly falls into this same period of continental condition of south-eastern Asia, though it is possible that in other parts of the Himalayan geosyncline marine invasion began before these eruptions came to an end. In Kashmir the sea returned only in Permian time, when the Zewan beds with their marine fauna were formed.

Fig. 212. *Martinia coreulum* Kutorga.

Before this invasion however, and after the close of the period of volcanic eruption, there occurred in Kashmir an interval of continental sedimentation, resulting in the formation of some 800 feet of shales and sandstones with a basal conglomerate, which, near the middle, enclose remains of the Lower Gondwana flora (*Glossopteris*, *Psygmophyllum*, *Gangamopteris*, *Vertebraria* etc.), fish (*Amblypterus*), and labyrinthodonts (*Archægosaurus*). These beds are correlated with the Talchir division of the Lower Gondwana, which will be more fully discussed in a later chapter. This division of the Lower Gondwana series is thus clearly pre-Permian (at least pre-Mid-Permian, since the succeeding Zewan beds contain the *Lyttonia* fauna). This was also the period of the late Palæozoic glaciation of other parts of India, South Africa and Australia. It may, however, be found that this period of glaciation actually corresponded to the time of the Mid-Carboniferous (Moscovian) emergence, since the beds which follow

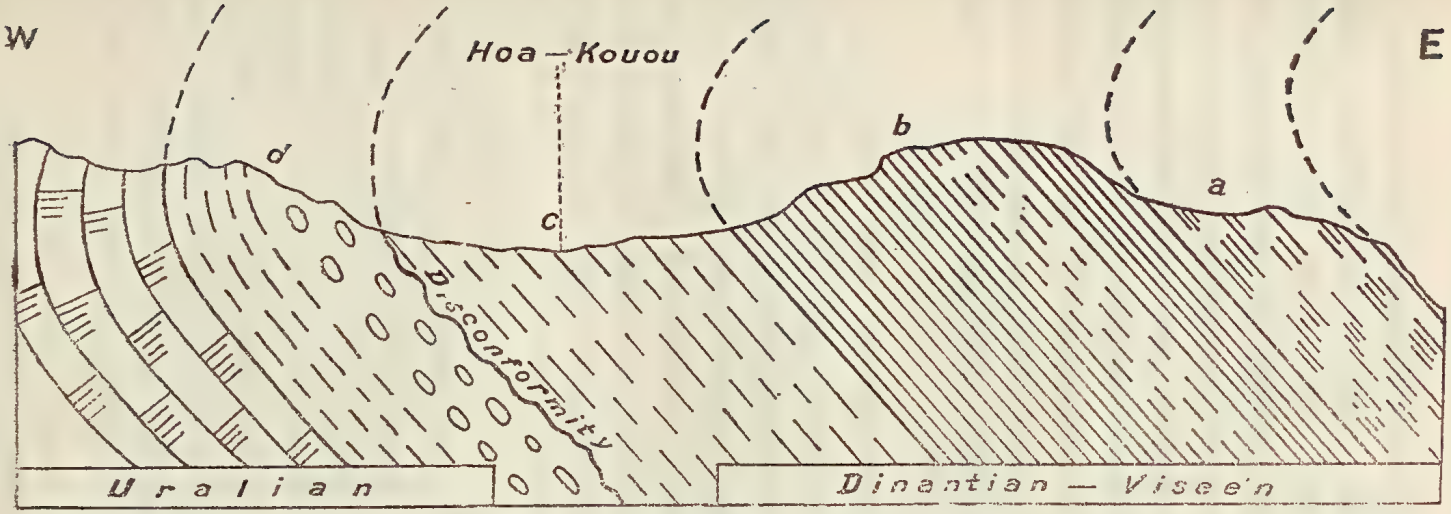


Fig. 213. Section at Hoa Kouou, east Yunnan, showing disconformity between Uralian basal conglomerate and Dinantian series (Div. a III). The strata are overturned. (Modified after Deprat).

a. Yellow marly shales with regular bands of small concretions and *Aviculopecten dupontesi* Mans. and *Productella spinulosa* (Deprat's h. IIIa) ..... 20 meters

b. Yellow-red friable marly shale with *Productella spinulosa* (Duprat's h. IIIb) ..... 50 meters

c. Black to blue shales with *Chonetes papilionaceus* Phill ..... 40 meters

Disconformity.

d. Basal conglomerate of Uralian.

e. Beds with *Fusulina multiseptata* (Uralian).

these glacial tillites in the Salt Range region of India, i.e. the Lower Productus limestone, may be of Gschellian or early Upper Carboniferous age. (See chapter IX.)

In the Spiti region, the Po SERIES of *Fenestella* shales, and shales and sandstones with a Culm Flora underlies the KULING Permian shale disconformably, and has a thickness of at least 2,000 feet. The fauna suggests possible equivalency with the Middle Carboniferous (Moscovian) in the lower part and with the *Fenestella* beds of Kashmir in the upper part. The latter may include Uralian. This will be more fully considered in the next chapter in connection with the overlying Permian shales.

Moscovian Time in China.

At present no true Moscovian or Middle Carboniferous is known in China, unless we refer the *Taiyuan series* to its basal part. As has however, been shown, this series is best regarded as the upper part of the Dinantian (Lower Carboniferous). The species referred to *Spirifer mosquensis* by Mansuy is a variety of *Spirifer bisulcatus* but not the true *S. mosquensis* Fischer (Fig. 184) which is unknown in China.

During Moscovian time, China was mostly dry land. In eastern Yunnan there are two limestone formations which may perhaps be regarded as sediments formed during this period. These are, the *Loatien limestone* (B. V, p.243) and the *Chouéitang limestone* (B. VI, p.243). These formations still contain some species found in the Dinantian, especially the Foraminifera of the Taiyuan series, but in addition they carry many new species, especially of corals and gastropods.* Mansuy suggested, that the character of the fauna of the Chouéitang limestone indicates transition between Dinantian and Moscovian.

* For description of these see Mansuy (Bibligraphy V, No. 10).

The waters in which these deposits were formed, were apparently not connected with those which covered Europe, but constituted an isolated provincial sea. (See map, Fig. 221). The European sea re-entered the Chinese basin in Uralian (Upper Carboniferous) time, spreading again more widely. North China was however not submerged until the beginning of Permian (Permo-Carboniferous or Artinskian) time, for everywhere beds of the latter age lie upon the eroded surfaces of the Taiyuan series.

Late Lower or Early Middle Carboniferous (Culm) In the Indian Ocean Region.

In the Malay Peninsula of Lower Siam a formation of the age of the Culm of western Europe has been found and its fossils described by Reed (60). The locality is Kuan-Ling-Soh, in the Patalung district (abt. Lat. 7°30′N., Long. 100° E.) The fossils occur in a very fine rock (silicilutyte) composed almost entirely of silica, with practically no lime but some alumina. It is of a whitish color, and usually breaks with a conchoidal fracture, but weathers chalky. The fossils are poorly preserved, mostly as external or internal moulds. A grit of varying coarseness, from the same locality, was without determinable fossils.

Only four species are specifically identified with certainty, these being (1) *Posidonomya becheri* Bronn var. *siamensis* Reed, a new variety, (2) *Athyris subtilita* Hall, (3) *Productus concentricus* Sarres-Kays., and (4) *P. laevipunctatus* Sarres. Of these No. 1 indicates the Culm or *Posidonomya becheri* zone of the Upper Carboniferous or Pendleside division of England (see p. 214), a horizon just overlying the Viséen, and therefore comparable to our Taiyuan series in age. Reed says that the species is scarcely separable from the typical *P. becheri* of the Culm. Several of the imperfectly identified species "seem to be identical or very closely comparable with species

occurring in beds of this age on the continent and in the south-west of England." *Athyris subtilita* of the American Carboniferous has also been identified from the Lower Carboniferous of west Europe, and the Viséen of Yunnan. It appears to be a form of wide geographic as well as considerable vertical range. The third and fourth species, *Productus concentricus* and *P. lævipunctatus*, are characteristic of the Culm of west Europe.

The rather close similarity of this fauna to the Culm fauna of western Europe is very striking. There is nothing positive to ally it with the Taiyuan or Viséen faunas of China or Indo-China nor with any of the faunas described from the Himalayan region. Culm is held to be represented by the lower part of the Po series of Spiti, but this contains only plant remains, marine fossils being apparently wanting. It is, of course, not impossible that a fauna of this type will be found in the Himalayan strata, and that at the end of Dinantian time - perhaps during the period of the deposition of the Taiyuan strata of the Chinese basin - the Burmese straits were open, permitting direct communication with Europe along the path of migration of the Viséen faunas. But in that case, the connection with the Chinese basin could not have been a pronounced one, otherwise there would be a more marked similarity of faunas. Possibly future discoveries will bring to light the *Posidonia becheri* fauna in China, as well as in the Himalayas, thus definitely solving the palæogeographic problem, but until this has happened we must consider the possibility of a circuitous connection of the Indo-Pacific region, either by way of North American waters, or by the Trans-Siberian route via the Mongolian geosyncline, as shown on the map of Viséen palæogeography (Fig. 148 p. 220).

In the southern part of the Malay peninsula, in the state of Pahang, etc., the oldest sedimentary rock *in situ* is the Raub Series (Scrivenor 67) with which is associated, in Pahang (abt. Lat. 3° N.,

Long. 103° E.) the Pahang volcanic series. This is comtemporaneous with it, but also continues into a later epoch. The Raub series forms a large part of the exposures in the low-lying land of the river valleys in the peninsula. The series is largely calcareous throughout, but with some non-calcareous shales, some of which apparently contain a certain amount of volcanic matter, and some contain carbon. Much of the limestone is crystalline, and fossils are poorly preserved. The genera recorded from it are *Orthoceras, Cyrtoceras, Gyroceras* and *Solenocheilus*, an ammonoid resembling *Xenodiscus*, and tubes resembling *Dentalium herculeum* de Kon. The age is believed to be Carboniferous, and the beds are either equivalent to the "Culm" beds of the Patalung district or they may be somewhat younger. Overlying the limestones in the Pahang region are Radiolarian cherts (Scrivenor 66), which are regarded as a part of the Raub series, and these are in turn disconformably succeeded by *Miophoria* sandstone, referred to the Rhætic. In Perak on the east coast (abt. Lat. 5° N., Long. 101° E.) however, the Raub series is followed directly by tillite, which undoubtedly is referable to the glacial period in which the similar Talchir tillites of the Salt Range of India and the corresponding tillites of Australia and South Africa were formed. As the Talchir tillites of India underlie beds which are probably of Upper Carboniferous age (see Chapter IX), the glacial period may coincide with the period of withdrawal of the waters of the mid-Carboniferous sea, in which case the beds of the Raub Series are either late Lower or early Middle Carboniferous.

Uralian Deposits in China

Southern China.

In Uralian time the sea transgressed widely over southeastern Asia. It re-entered the Chinese basin along the Himalayan geosyncline, and extended southward into Tonking and Laos (Indo-China), where beds of Uralian age rest unconformably upon the older

folded strata (Silurian, Devonian and Dinantian). In parts of eastern Yunnan too, Uralian beds rest disconformably, and with a basal conglomerate, upon the older Dinantian (Div. A III.) as at Haokeuou (Fig. 213 p. 291) where the entire series is overturned. The transgressive character is shown by the fact, that the Uralian here found is

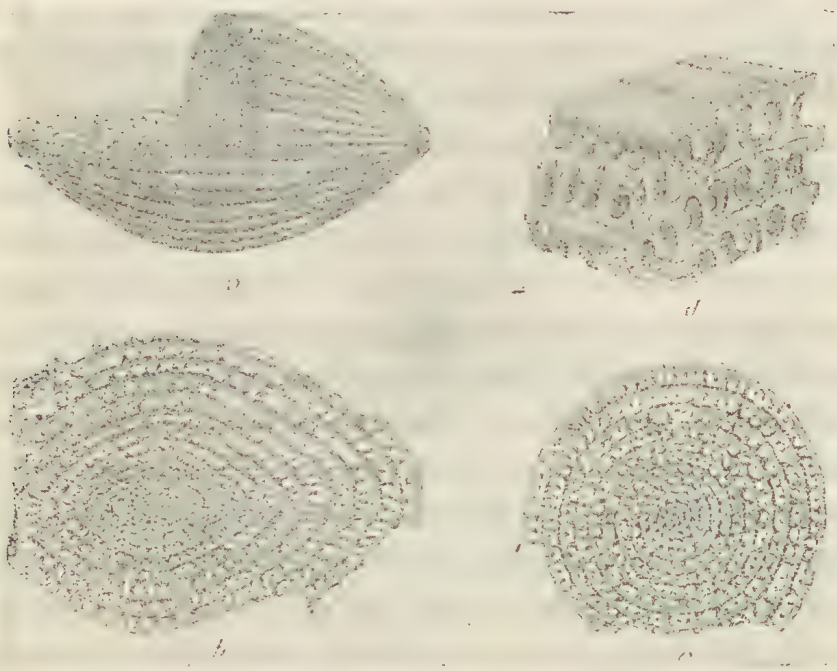


Fig. 214. *Neoschwagerina craticulifera* (Schwager); *a*, Individual sectioned to show interior × 12; *b*, longitudinal median section showing the strong transverse septa (basal skeleton) × 16; *c*, transverse section showing the longitudinal septa or roof skeleton × 16; *d*, diagrammatic section to show the relationship of the transverse and longitudinal septa within the chambers (i.e. basal and roof skeleton) much enlarged (After Schwager).

upper Uralian with *Fusulina multiseptа* (Zone 6 of list below, i.e. Lower Permian or Permo-Carboniferous of Frech). In other sections, the Uralian rests upon the Loation or the Chouéitang formations (Div. B. V or VI, p. 243) and in the Kütsing region upon late Dinantian. The Uralian, as classified by Deprat, has a thickness of about 1,200 meters in Yunnan, though a part of this may be referable to the Permian.

It is mostly formed of limestones with Foraminifera, and is divisible into the following zones in descending order:

Upper Uralian (Deprat)—Lower Permian (Frech)

10 Zone of *Neoschwagerina multicircumvoluta* Depr.
9 ,, ,, *Neoschwagerina craticulifera* (Schwag.) (Fig. 214).
8 ,, ,, *Schwagerina princeps* (Ehrenberg) (Fig. 215).
7 ,, ,, *Fusulina incisa* Schellwien.
6 ,, ,, *Fusulina multiseptata* Schellw. and *Doliolina aliciæ* Deprat.
5 ,, ,, *Doliolina claudiæ* Deprat.
4 ,, ,, *Productus* cf. *compressus*.
3 ,, ,, *Fusulina kattaensis* Waagen.

Lower Uralian (Deprat).—Typical Upper Carboniferous (Frech.)

2 Zone of *Fusulina tchengkiangensis* Deprat, and *F. regularis* Schwager (Fig. 216.).
1 Zone of *Fusulina brevicula* Schwager (Fig. 217) and *F. regularis* Schwager.

Disconformity

Sub-Formations: Choucitang or older beds.

It is quite possible that, as Frech has suggested, zones 3 to 10 should be classed as Lower Permian or Permo-Carboniferous, which would indicate that the transgression took place in late Uralian and in Permo-Carboniferous time, as is the case all over north China. The zones in question contain species which are also found in the *Productus limestone* of India.

Central China.

Nanking Hills. It is not yet known with certainty whether true Upper Carboniferous or Uralian beds are present in the Nanking Hills of Kiangsu province. Present evidence seems to indicate that

beds of the Shansi series (Permo-Carboniferous) follow disconformably upon the upper Viséon beds. Whether any representative of the Taiyuan series is present, also remains to be determined. The succession of formations, as now understood, for the Nanking region is given on a subsequent page.

Fig. 215.

Schwagerina princeps (Ehrenberg). *a*, *b*, front and end views of entire shell ×1½; *c*, part of a sectioned shell to show structure, × 6 (After Schwager).

YANGTZE GORGES. (Fig. 218). In the Yangtze gorges above Ichang, especially in the Wushan gorge, the SINT'AN SHALE (Dinantian or older) is succeeded by the great WUSHAN LIMESTONE, which has a thickness of about 1,200 meters (4,000 ft.). This consists of dark gray or blackish limestones, which include shale layers, and some anthracite coal beds at 350 and 600 meters above the base, respectively. Much chert occurs in the lower part.* From the lowest layers of this limestone, a fauna has been obtained which resembles the Gschellian fauna of Russia, or that of the Salt Range of India. This fauna includes *Schwagerina sp.*, *Lonsdalcia chinensis* Girty (Fig. 219), *Michelinia favositoides* Girty, *Geinitziella chinensis* Girty, *Fistulipora waageniana* Girty, *Spirifer blackwelderi* Girty (Fig. 220), and undetermined species of other brachiopods, etc. *Geinitziella chinensis* was again found together with *Batostomella meekana* Girty, from 240 to 300

Fig. 216.

Fusulina regularis Schellwien. Outline of entire shell × 3½ (After Deprat).

* For description of section see Willis and Blackwelder Research in China, Vol. I. For description of fossils see Girty, Ibid., Vol. III.

meters above the base, and undetermined species of *Chonetes*, *Ambocœlia* (cf. *A. planiconvexa*) and *Clyothyris*, at 350 meters above the base. The higher beds have so far yielded no fossils.

It is most probable that the greater part of the Wushan limestone is of Uralian (Upper Carboniferous), Permo-Carboniferous, and perhaps Permian age.

Fig. 217. *Fusulina brevicula* Schwager; *a*, entire individual sectioned to show interior × 9; *b*, cross-section × 12; *c*, partial longitudinal section × 12 (After Schwager).

The Wushan limestone is succeeded by the red beds of the Kweichou series (Willis) which are of late Permian or in part of Triassic age.

(See further, sections under Permian.)

Indo-China etc.

Late Carboniferous or Uralian beds are known from Tonking and Laos where they are especially represented by the *Productus* limestone of Mansuy. This probably represents late Uralian, containing elements suggestive of the Permian. Mansuy considers that it shows

closer affinities with the Uralo-Permian beds of the Ural mountains than with those of the Himalayas or the Salt Range. Brachiopods predominate in the fauna, comprising 115 species out of a total of 135 forms described. Of these some 65 percent are related to, or identical with, late Uralian species of Russia. While several horizons seem to be represented, the greater portion of the series belongs to the horizon of *Schwagerina princeps* (For list of the fauna see Mansuy V, 20, pp. 95-97, and for description, Mansuy V, 14, 15, 18.).

Fig. 218.

Columnar section of the Carboniferou and enclosing beds on the Yangtze (Modified after Willis and Blackwelder).

It might be suggested that this late Uralian horizon has not yet been found in the Himalayan region, where beds apparently of Gschellian age are disconformably succeeded by beds of Middle (?) Permian age. It may be that erosion in early Permian time has removed all of them, or that those portions of the disturbed strata of that mountain system, which were formed in the center of the geosyncline, may still retain them, though they have not yet been discovered. This is one of the problems for future investigation. Limestones with *Spirifer lydekkeri* Diener, a characteristic fossil of the Zewán beds of the western Himalaya (Spiti and Kashmir) occur at Ban - Lat - Cok in upper Laos. What is

probably a similar early Uralian horizon is found in the Yên-minh district of Tonking, where limestones at Ma Pi Leun and Yan Chai Lung carry *Productus scabriculus* Martin, *P. cora* d'Orbigny, and *Marginifera* cf. *involuta* Tschern.

Finally late Uralian beds with *Spirifer nikitini* Tschern. have been recorded from the Lang-son quadrangle of Tonking, and from the Tran Ninh plateau of Laos. In the latter region an associated

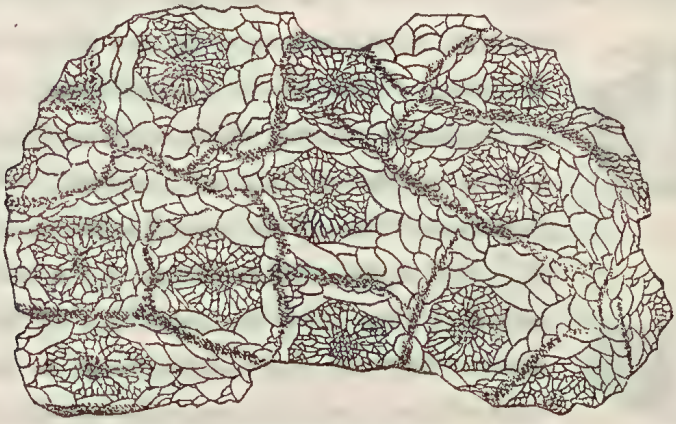


Fig. 219. *Lonsdaleia chinensis* Girty. Section.

fauna, mostly of new species, has been obtained. Some of the so-called Permo-Carboniferous limestone of Upper Siam may also include beds of Uralian age.

From Padang Sumatra, Fliegel (22b) has described a fauna which he considers to be of Upper Carboniferous age, but which is here referred to the base of the Permian (Permo-Carboniferous) (See Chapter IX).

Geographic Development in Later Carboniferous Time.

According to all the evidence available, the Moscovian or Middle Carboniferous was a period of shrinking seas and of the extension of continental deposits which commonly carry beds of coal

and the remains of a distinctive flora. River flood plains, dotted over with coal swamps, and composed of sands and clays brought from the old land of Atlantica, became wide-spread in western Europe, replacing the marine waters in which the Dinantian fauna had flourished. This fauna probably continued for a time in the Atlantic waters, and in local embayments of these waters in England, Belgium and elsewhere. But it is extremely unlikely that these embayments from the Atlantic had any connection with the great relict interior sea of Russia. As we have seen this sea was *par excellence* the home of the Lower Carboniferous (Dinantian or Donjetian) fauna, which continued here during a long period of time as measured by the great thickness of the calcareous sediments which enclose it. This fauna still continued for a considerable period of time after the deposition of those sediments which are definitely referred to the Lower Carboniferous, and the beginning of the formation of the sediments definitely referred to the Middle Carboniferous or Moscovian. The line between the two series is drawn at the level where a new fauna, characterized especially by *Spirifer mosquensis* (Fig. 184) makes its appearance in the basin. There is no evidence that this fauna developed within the Russian basin, for transition types are lacking, and the characteristic elements of the two faunas are sharply delimited. We can only hold that the new fauna was an exotic one invading this territory. At first it existed side by side with the older fauna, but as this gradually died out or became modified the totality of the aspect of the fauna became changed.

Fig. 220.
Spirifer blackwelderi Girty, enlarged × 2.

The question then arises, where was the home of this new fauna, where was its place of origin and center of distribution? If we look to the Boreal sea, we are confronted with the fact that this was in

uninterrupted connection with the Russian basin throughout Dinantian and Moscovian time; and we must conclude that, if the new species arose in the Boreal sea, some of their prenuncial types, showing intermediate characters between the Dinantian and Moscovian forms, should have wandered into the Russian basin. But if such exist they have not been made known.

On the other hand, we can hardly regard the Atlantic as the home of this new fauna, for where the new fauna occurs in regions bordering that water body as in Andalusia and in north Africa, it appears to be fully distinct from the preceding Dinantian fauna. Moreover, the lingering of the almost unmodified Dinantian fauna in western Europe, during the early part of the period characterized by spreading flood plains, and its recurrence in intercalated beds in the higher Belgian coal series, suggests that it was the Dinantian fauna which lingered in the Atlantic and that the successive marine intercalations in the coal beds of Belgium, mark repeated invasions from that water-body, and indicate a total severance of these waters from those which filled the Russian basin.

Taking the known facts into consideration, it appears that we must turn to Asia as the place of origin and early distribution of the new fauna, though so far as we can judge, this fauna soon became extinct in its home land. And it is to China, that all the available evidence seems to point, as the region where the Dinantian fauna became modified into the Moscovian fauna. To announce this as a final conclusion would be premature and unwarranted, as the study of the Chinese faunas has not progressed far enough. But some evidence for such a supposition certainly exists, and in the case of one typical species of the Moscovian - perhaps the most typical, i.e., *Spirifer mosquensis*, the facts seem to point unmistakably to China as the place of its evolution, and to *Spirifer bisulcatus*, the wide-spread Upper Dinantian form, as its ancestor; for we find both in the extreme

north west and in the south west of China varieties of *Spirifer bisulcatus* which clearly indicate development in the direction of *S. mosquensis*. In their young stages these forms retain all the characters of the ancestral *S. bisulcatus*, but the adult stages show modifications which have led previous observers to class this form as *Spirifer mosquensis*. It is not so much with the adult stages of that species, that the Chinese forms agree, but rather with the immature stages of the typical Russian form. Thus these Chinese mutations are in all respects intermediate between *S. bisulcatus* and *S. mosquensis*, and by further acceleration in development would produce the typical *mosquensis* characters. These Chinese forms belong to the Taiyuan series which represents the deposits formed during the period of greatest expansion of the Dinantian waters within the Chinese basin. It must be recalled that the Chinese basin was one of marked isolation, even in the Taiyuan period, this isolation furnishing the conditions requisite for the modification of the fauna thus cut off from its contemporaries. Once the impetus was acquired for the development in the new direction, and progress in this direction made to the extent that it could not be checked, this development would continue, even after the forms affected had entered into a more cosmopolitan field. Once established, the new types could spread as far as proper geographical and other environmental conditions permitted. So far then as the most diagnostic species of *Spirifer* of the Moscovian fauna is concerned, it seems certain that the impetus for its development was acquired in Chinese waters, though the species never developed far enough in these waters to become fully established, at least so far as we are able to determine from the faunas of the formations preserved. It is true that the period of deposition of the Taiyuan series was followed by a prolonged period of erosion, especially in north China, so that higher beds of this series may have been removed. Still it is doubtful if true Moscovian with typical *Spirifer mosquensis* ever existed in China—

that fauna received its developmental impetus in China, but probably completed its development for the most part after leaving the basin.

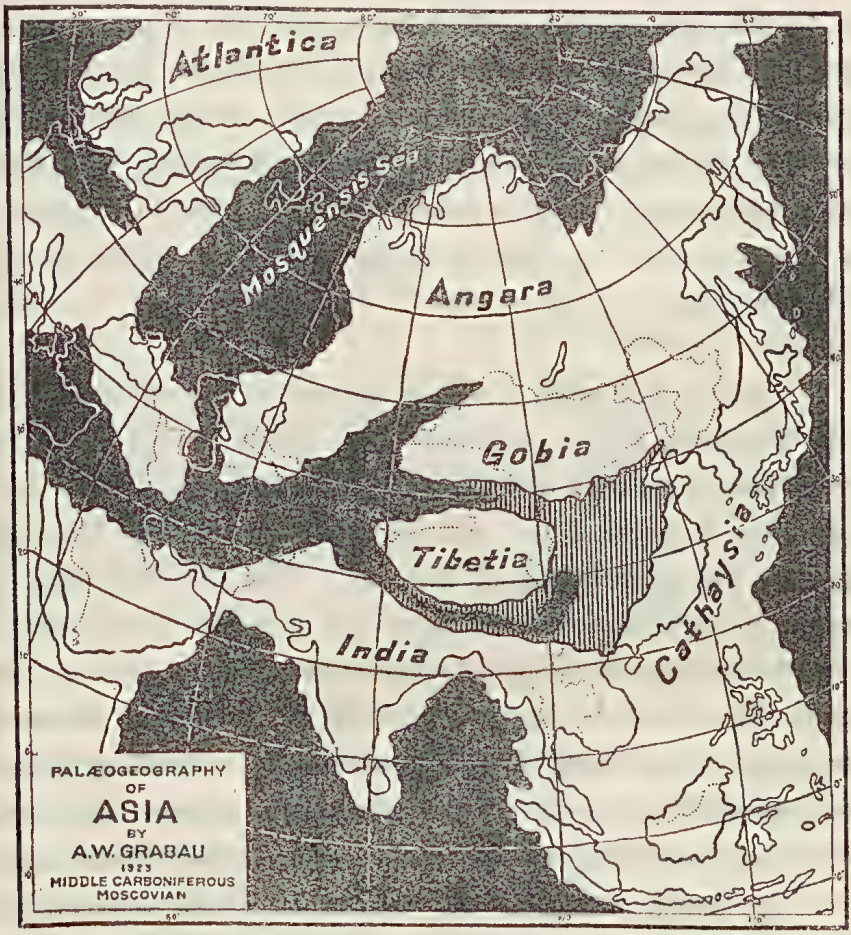


Fig. 221. Palæogeographic map of Asia, showing the probable distribution of land and sea (black) in Moscovian time. The vertical lining within the Chinese basin, and the Himalayan and Nanshan geosynclines indicates the extent of the Taiyuan transgression. The small black area in the southwestern part of the basin represents the residual Moscovian sea of Yunnan. It is possible that during the Taiyuan transgression connection with the Indian Ocean was established, and part of the Malay Peninsula was flooded.

On the Palæogeographic map Fig. 221, an attempt has been made to present the essentials of the geographic conditions of Moscovian time in Eur-Asia, so far as known. The eastern-most region in central Asia from which the Moscovian fauna has been recorded, is the

Tianshan. We are at present unable to determine the precise relation of this fauna to that of the Taiyuan series, and it may be that this Asiatic representation of that fauna bears the stamp of progress towards its typical Russian expression. The Moscovian fauna has been recorded from Arabia Petraia and from regions farther west in north Africa, as well as from Balia Maden in north-western Asia Minor. Thus it appears that the south Asiatic water-way was in existence at that time essentially as outlined on the map. The connection with the Russian basin is made by way of the Caspian depression, where Karpinsky located it.*

As has been noted, a certain amount of transgression of the sea in Moscovian time is indicated in northwest Russia where this series of formations rests directly upon Devonian rocks. This transgression was, however, a local one only, for the keynote to Moscovian geography was a shrinking of the seas. That the Moscovian sea remained in connection with the Boreal sea, is shown by the presence of the Moscovian fauna in the delta region of the Lena River in north Siberia. The question then arises, why is the typical Moscovian fauna absent from North America, where the succeeding Uralian fauna is so well developed. The answer to this question lies in the character and conditions of the North American Carboniferous basins.

In North America, the formations which represent the Middle Carboniferous or Moscovian of Europe, are the Potsville and Kanawha series and perhaps a part of the Alleghany series. In the Appalachian region, these formations originated as alluvial fans or river flood-plain deposits, dotted over with coal swamps, and formed primarily by streams which brought the waste of the land from Appalachia. Marine beds are practically negligible, except in the Alleghany series where they form a few small intercalations. In the

* See the Palæogeographic maps of European Russia by Karpinsky reproduced in Kayser's Lehrbuch der Geologie Vol. I.

southern (Ouachita) geosyncline, deposits of black mud were formed by rivers from the low land to the south, and some of these enclose a few marine organisms. Such is the Morro formation of Arkansas which contains *Pentremites* and other forms, suggestive of a local derivation from the late Mississippian fauna. Similar faunas, regarded as of Pottsvillian age, have been obtained near Virginia City, Montana and elsewhere in that state, their Mississippian affinities being such that they were originally referred to that system.

These facts seem to point to the distinctness of the American marine basins from those of Europe in Moscovian time, and it is possible that the American waters were in connection with those of the Pacific rather than with the Boreal Sea, which at that time was probably inhabited by the typical Moscovian fauna. Careful future comparative study of forms must determine whether at this time there was any connection between the European and American waters.

With the opening of Upper Carboniferous or Uralian time a positive eustatic movement of the sea recommenced. As we have seen the lower Uralian, or Gschellian, widely transgressed the previous continents, resting on undisturbed continental Devonian in Bear Island in the Arctic region, and on folded Dinantian and older strata in the eastern Alps of Europe. In Asia too, beds of Gschellian and younger age overlap the older formations, this having already been noted for the Tianshan region and for southern China. It was indeed in Uralian time that the Chinese basin was again flooded by the extensions of the European seas, but such flooding was apparently confined to south and central China, north China not being invaded by the sea until Permo-Carboniferous time.

The Uralian fauna of Europe has a strong American element and there can be no question but that at that time the water-ways to and from the Boreal Sea were open in both directions. Whether the

new elements originated in American waters, or wandered into them as they did into the European waters, can at present not be determined. The presence of some of these forms in the older (Pottsville) faunas may indicate an American origin. On the other hand, these elements may have arisen in some Pacific province. In any case, they could only have reached Europe by way of North America and the Boreal Sea, for direct connection with the Pacific, across Asia, was not in existence at that time since, according to all the available evidence, the Mongolian geosyncline was not again flooded until early Permian time. So far as our present knowledge permits us to judge, the Uralian transgression continued into Permian time in so far as Asia was concerned, though in north Europe great changes, resulting in the formation of wide-spread continental beds (Rotliegendes) occurred, followed by temporary advances and subsequent withdrawals of the sea, and the development of the great salt basins.

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CHAPTER IX.

THE PERMIAN SYSTEM.

The Permian system, formerly often called Dias because of its two-fold development in Germany, is the last of the Palæozoic systems, and is now commonly recognized as distinct, though by some it is included with the later Carboniferous and Dinantian in the *Anthracolithic system*. Considered as a distinct system, it admits of the following three-fold subdivision based on the west European development.

Upper Permian or Thuringian
Middle Permian or Saxonian
Lower Permian or Artinskian (Autunian)

Another subdivision is that adopted for the marine Permian or Dyas by Frech and Noetling, which is as follows:

Neo-Dyas (with Ceratitic Ammonoids)

2. Upper division
1. Lower or Djulfa division

Palæo-Dyas (without Ceratites)

2. Upper or Sosio stage
1. Lower or Arta (Artinskian) stage.

In Europe the marine Permian appears separable into two geographic provinces, the northern or Boreal, with its chief extension into Russia, and the southern or Mediterranean (Tethys), the two being separated by the land-mass of Palæo-Caucasia.

The North European Basins.

The Boreal development of the marine Permian is best exemplified by the succession of formations which has been preserved

on Spitzbergen where all divisions of the series seem to be represented, from the Upper Carboniferous to the Trias, as follows:

Super-Formation: Marine Triassic, *Myalina* shales

PERMIAN

3. Upper shales with *Pseudomonotis*
2. Limestone with *Retzia nathorsti* and *R.* (*Hustedia*) *mormoni*
1. Artinskian, chert and shales, 375-400 m., with *Productus cancriniformis* (Fig. 222), *P. postcarbonarius*, *Derbya robusta*, *Spirifer alatus*, *Spirifer keilhavi* etc., together with numerous sponge spicules (*Pemmatites*).

UPPER URALIAN: Spirifer limestone (*Schwagerina* stage).

Far to the south in the Boreal-Russian basin at Nishni-Novgorod in the Volga Valley, the succession is as follows in descending order:

3. Limestones with *Macrodon kingianum*, *Leda speluncaria*, *Solemya* etc., and with gastropods, while brachiopods are more rare. Beds with *Modiolopsis* at the top.
2. Limestones with *Productus cancrini*, *Dielasma elongata*, *Strophalosia horrescens* (Fig. 223), *Pseudomonotis speluncara*, *Bakewellia ceratophaga*, *Edmondia murchisoni*, *Schizodus obscurus*, and gastropods (*Turbo*, *Pleurotomaria*, *Loxonema*, etc.) and *Fenestella reniformis*.
1. Siliceous and dolomitic limestones with Fusulinas, corals, brachiopods (*Dielasma elongata*,

Strophalosia horrescens); Pelecypods: (*Pseudomonotis speluncaria, Pecten sericeus, Bakewellia ceratophaga, Allorisma elegans*).

Still farther to the south in the Donetz basin, the Permian, here some 2,000 meters thick, shows the following subdivisions in descending order:

3. Upper Permian—(Tartarian Series) composed of red and green marls and shales with friable sandstones, and with gypsum and rock-salt.
2. Middle Permian—dolomites with nautiloids (*Metacoceras, Temnocheilus, Asymptoceras*), gastropods and pelecypods, and the brachiopods *Productus leplayi, Dielasma elongata* etc., and with *Schwagerina princeps.*
1. Lower Permian or Artinskian—alternations of shales and limestones with *Productus inflatus, P. nebraskensis, P. semireticulatus, Enteletes carnica, Derbya crassa;* and with pelecypods and gastropods. At the top are sandstones with plant remains (*Asterophyllites, Sphenophyllum, Pecopteris arborescens, Cordaites*, etc.)

The eastern border of this basin was formed by the Uralian old land, along the margin of which abundant sediments were carried by streams into the sea. This resulted in the formation of a great series of sandstone deposits intercalated with calcareous beds, which mark the periodic extension of the sea. This is the condition in the government of Perm, the type region of the Permian deposits of Russia. The Lower Permian, or Artinskian, begins with conglomerates, sandstones and intercalated limestones, which rest with a slight discordance upon the Uralian. The fauna consists of a mixture of

Carboniferous and Permian species together with many forms apparently restricted to this horizon. The most important of these are the goniatites and related cephalopods, the following being most common: *Gastrioceras* (*G. jossæ* (Fig. 224), *G. suessi*), *Paralegoceras tschernyschewi*, *Agathiceras stuckenbergi*, *A. krotowi*, *Popanoceras sobolewskianum* (Fig. 225), *P. kingianum*, *Thalassoceras gemmellaroi*, *Pronorites præpermicus*, *P. postcarbonarius*, *Medlicottia artiensis*, *M. orbignyana* (Fig. 226), and *Propinacoceras sakmaræ*. The important brachiopods are *Spirifer keilhavi*, *Productus artiensis*, *P. præpermicus*, and *P. cancriniformis*. Plants are abundant in the continental sediments, these including *Calamites gigas*, *Cordaites*, *Callipteris conferta* (Fig. 227), *Pecopteris unita*, etc.

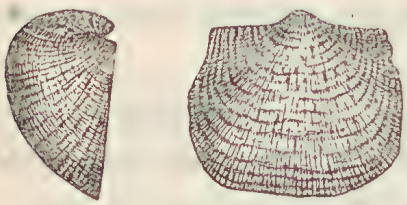

Fig. 222.
Productus cancriniformis.

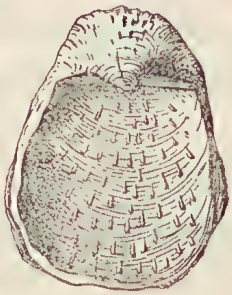

Fig. 223.
Strophalosia horrescens de Vern.

The Artinskian is succeeded by the KUNGURIAN limestones which enclose the same brachiopods as the beds below but carry no cephalopods. A transgression of the sea is thus indicated but this was of short duration, for with the beginning of Mid-Permian time the sea again withdrew, and beds of shales with gypsum and rock salt were formed as marginal lagoon deposits, these alternating with sandstones with plant and reptilian remains, and with calcareous beds containing *Productus horridus* (Fig. 228), *P. cancrini*, *Camarophoria schlotheimi*, etc , and finally with beds containing brackish-water mollusks.

In the Upper Permian the non-marine conditions continued to spread, the deposits being terminated by the TARTARIAN red beds with salt and gypsum, followed in turn by similar beds of Triassic age.

In west Europe, the newly formed Armorican and Variscian mountain chains (see map Fig. 229) completely isolated the basin of north Germany and its extension into eastern England, and transformed it into an arid basin which was slowly filled by the waste from these mountains, spread by intermittent streams over the floor of the depression. Thus was formed the Lower Permian ROTLIEGENDES, a great formation of red sandstones with a thickness of a thousand meters. The transgression which is signalized by the occurrence of the Kungurian beds, eventually submerged this desert basin of north Europe, killing the fish fauna of the rivers and lakes which by this time had come to characterize that basin. In this manner was produced the remarkable "KUPFERSCHIEFER" which overlies the Rotliegendes of some sections in Germany. Then followed a period of limestone formation, producing the German ZECHSTEIN and the English MAGNESIAN LIMESTONE in which the fauna of the Boreal-Russian sea existed for a time, certain forms being so numerous as to produce reef-like accumulations of limestones. Through the closing of the inlet which had permitted the entrance of the Russian sea, the north European basin was converted into an inland salt lake, the progressive evaporation of the waters of which produced the succession

Fig. 224.
Gastrioceras jossæ M. V. & K.

Fig. 225a.
Popanoceras sobolewskianum M. V. & K.

of deposits of anhydrite rock-salt and mother-liquor salts, for which this region is famous. Two successive floodings of the basin are indicated by the deposits, the evaporation of the waters in each case being complete. The highest series of salt beds corresponds essentially to the period of deposition of the Tartarian continental beds.*

Fig. 225b. *Popanoceras sobolewskianum* M. V. & K. Ventral view.

There is one outstanding feature of the Permian of the northern basin which deserves to be emphasized. This is the essential continuity of a large part of the preceeding Upper Carboniferous fauna through the greater part of the series; though there are also many species which make their first appearance. These are probably emigrants from the southern Permian basin, connection with which was maintained at least during the earlier periods. Essentially similar conditions are known to occur in the interior deposits of North America, especially those of Artinskian age, and here, as in Russia, a considerable number of Carboniferous species continue into the Permian deposits. Moreover, many of the species of the two regions are identical or at least very closely related, and it seems certain that these water bodies were for the most part in continuous connection through the Boreal sea, of which they formed virtual extensions. (Fig. 231, p. 326).

Fig. 226. *Medlicottia orbignyana* M.V. & K.

The Southern European Basin.

(Map Fig. 229.)

The south European sea, the Tethys of Suess, which played so important a role in Mesozoic palæogeography, was for the first time

*For further details see Grabau 39, 40, 41.

developed to its full extent in Permian time after the formation of the Armorican and Variscian mountain chains. This sea was in direct connection with the water bodies which covered Asia at that time, while a limited connection with the north European basin also existed. Along the northern border of this southern sea, extensive deposits of alluvial material were formed by the rivers from the newly

Fig. 227. *Callipteris conferta* (Brgt.)

raised mountains. Portions of these deposits are now included in the younger folds of the Alps, being especially well known from northern Italy. Here, near Pisa, the Lower Permian is entirely represented by formations of this nature, these being locally known as "Verrucano". The series admits of a three-fold division as follows in descending order:

3. Hard micaceous shales and sandstones with the following plant remains: *Walchia pinniformis* (Fig. 230), *W. flaccida*, *W. baiera*, *Ginkgo primigenia*, *Tæniopteris multinervis* and *Callipteris conferta* (Fig. 227).

2. Sandstones, conglomerates, and violet clay-shales, with the following plant remains: *Callipteris conferta, C. obliqua,* and *Sphænophyllum (Trizygia) arcangeliana.*

1. Shales with *Dictyopteris neuropteroides, Asterophyllites radiiformis, Sphenopteris lebachensis, Sp. böckingiana, Pecopteris dentata, P. hemitelioides, P. oreopteridia,* etc.

Subformation: Coal and anthracite-bearing beds (Upper Carboniferous).

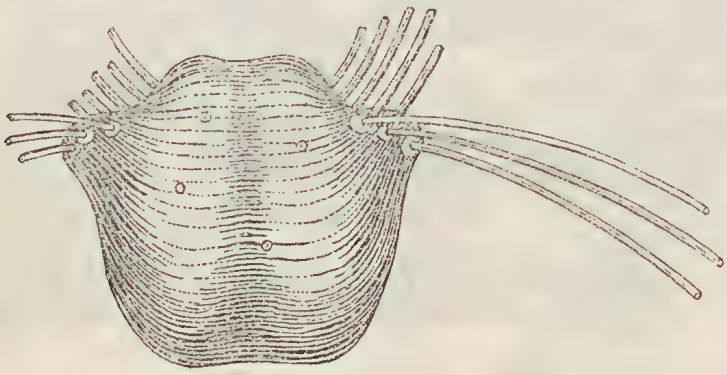

Fig. 228. *Productus horridus* Sowerby.

In general, this entire series corresponds to the Rotliegendes of the north European basin.

Farther south, in the region then characterized by open waters, the corresponding marine beds of the Lower Permian were deposited. These are today known from only a few localities, for subsequent disturbances and erosion have largely destroyed them, and deposition of younger beds has covered the remainder to a large degree. The best known occurrence is that on the island of Sicily, where in the province of Palermo, some remnants of these rocks are uncovered in the valley of the Sosio river. This so-called Sosio

Limestone, admits of a two-fold division on a lithological basis; a lower compact gray or white *Fusulina* limestone (*Calcare compatto*) and an upper porous coarse-grained limestone (*Calcare grossolano*). There appear to be several faunal horizons in this series of rocks,

Fig. 229. Palæogeographic map of Asia showing the probable distribution of land and sea (black) in Mid-Permian time. The vertically lined area in north China indicates the extent of the Shansi Sea, and its deposits.

representing Lower and perhaps Middle Permian. The faunas, while having a certain relationship to those of north Europe, are on the whole more intimately related to those of central Asia, many of the more remarkable species being restricted to this southern region and

its Asiatic extension. Among these are: *Enteletes waageni* Gemm. (*E. oehlerti*), *Geyerella gemmellaroi* Schellw., *Martinia polymorpha* Gemm., together with the genera *Richthofenia* and *Lyttonia*. Goniatites are also abundant, and very characteristic. A similar fauna has been found in some of the deposits of the Carnic Alps.

Fig. 230. *Walchia pinniformis* Sternb.

The marine Upper Permian of the southern European basin is best known from the deposits known as BELLEROPHON LIMESTONE, which in the sou-

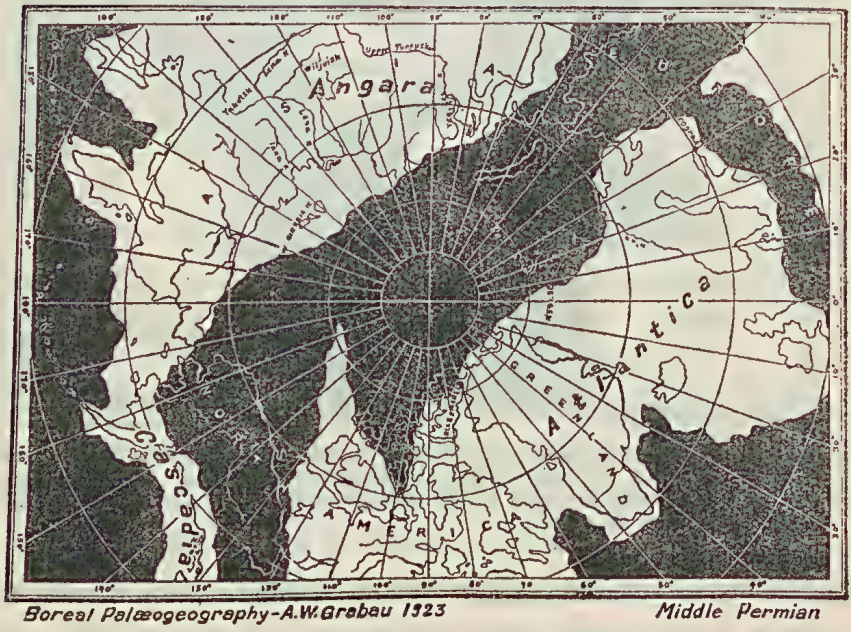

Fig. 231. Palæogeographic map of the present Arctic region, showing the probable distribution of land and sea (black) in mid-Permian time, and the route of migration of marine faunas between North America and Eur-Asia.

thern parts of the Eastern Alps, rests upon older Permian sandstones, and is succeeded by Triassic sandstones. It consists of dark, mostly bituminous limestones, dolomites, cellular dolomites, (*Rauchwacke*) ash, and gypsum, and apparently represents a shallow-water, partly lagoonal, deposit along the margin of the Upper Permian sea.

The fauna of this formation is on the whole a peculiar one containing remarkably modified Athyroid shells (*Comelicania, Janiceps*), and numerous species of *Bellerophon* (especially *B. peregrinus* Fig. 232), which are closely related to, or identical with species found in the Upper Productus limestone of India. Pelecypods (*Aviculopecten, Bakewellia, Pleurophorus, Allorisma, Schizodus*, etc.) are common and nautiloids, suggestive of the older series (*Pleuronautilus fugax, Metacoceras hoernesi*) occur. Among the goniatites, *Paraceltites* should especially be mentioned, this genus also occurring in the Permian of China. With these also occurs the characteristic Indian coral *Lonsdaleia indica* W. & W.

Fig. 232. *Bellerophon peregrinus* Lbe. Bellerophon Limestones of Mediterranean.

The Permian System in Asia.

The Standard Section.

The standard section of the Permian in Asia is that of the Salt-Range in northwest India. Because of its importance it is here given in some detail for comparison with other sections. The original subdivisions by Waagen, together with the modifications suggested by Noetling, are shown in the following table to which is added the suggestion of the hiatus and disconformity between the Lower and Middle Productus limestone.

Table of the Upper Palæozoic beds of the Salt Range.

Super-formation: Triassic Ceratite Marls.

Hiatus.*

Waagen's Subdivisions.		Noetling's Subdivisions.	
Upper Productus Limestone (130 feet and less)	CHIDERU BEDS Marls and Sandstones JABI BEDS Sandy limestones (with cephalopods) KUNDGHAT BEDS Sandstones	Upper Productus Limestone or CHIDERU GROUP	Zone of *Euphemus indicus* „ „ *Medlicottia wynnii* (Fig. 233) „ „ *Bellerophon impressus* „ „ *Cyclolobus oldhami* „ „ *Derbya hemisphærica* „ „ *Productus lineatus*
Middle Productus Limestone (270-410 feet)	KALABAGH BEDS Crinoidal limestones, marls and dolomites. VIRGAL BEDS Cherty limestone	Middle Productus Limestone or VIRGAL GROUP KATTA BEDS	Zone of *Xenaspis* (*Xenodicus*) *carbonaria* (Fig. 234) „ „ *Lyttonia nobilis* „ „ *Fusulina kattaensis***
Hiatus and Disconformity?			
Lower Productus Limestone 27 to 70 feet	KATTA BEDS Arenaceous limestones and calcareous sandstones AMB BEDS (-Upper speckled sandstones) Calcareous sandstone	Lower Productus Limestone or AMB GROUP	Zone of *Fusulina kattaensis**** „ „ *Spirifer marcoui*
Pendschab Series 400 to 600 feet	SPECKLED SANDSTONE (Middle and Lower) Mottled sandstone followed by gray and blue clays - 100 ft. BOULDER CLAY Glaciated boulders in a fine matrix 100-200 ft.	WARCHA GROUP DANDOTE GROUP TALCHIR GROUP	Lavendel clay. Speckled sandstone Olive-green z. of *Conularia lævigata* Sandstone z. of *Eurydesma globosa* Boulder Clay
Hiatus and Unconformity.			

Sub-formation—Lower Cambrian.

Noetling and Frech regard the entire PRODUCTUS LIMESTONE as Permian, chiefly because there appears to be a transition into the overlying Triassic. Tschernyschew, on the other hand, correlates the lower Productus limestone with the Gschellian of the Urals, *i. e.* the zones of *Spirifer marcoui* and *Omphalotrochus whitneyi*. The middle Productus limestone he correlates with the *Uralian*, *i. e.* the beds with

* See Chapter X. ** According to Noetling. *** According to Waagen.

Productus cora and the *Schwagerina* beds. Finally he refers the upper Productus limestone to the Artinskian or Lower Permian (Permo-Carboniferous of the Russian geologists). It must, however, be noted that *Lyttonia* and associates are absent from the Russian Upper Carboniferous, though widely distributed in Asia.

There is however another possible explanation, namely that the Salt Range section is incomplete, and that, while the lower Productus limestone (mostly sandstone) is the equivalent of the Gschellian of Russia, it is separated from the higher members by a disconformity which cuts out the Uralian and possibly the Artinskian, so that the middle and upper Productus limestones represent later Permian. This supposition is borne out by the great variation in thickness of the lower Productus limestone (sandstone), for at Amb, where it is most fossiliferous, the thickness is only 27 feet, while at Katta it is 55-66 feet (Waagen 96b, pp. 116, 158).

Fig. 233.
Medlicottia wynnii Waagen. Ventral view.

If this supposition is correct, the break in succession probably lies above the zone with *Fusulina kattaensis* (Katta beds). Waagen himself considered the lower Productus limestone as possibly Carboniferous, and he classed the *Fusulina kattaensis* beds (6 to 10 ft. thick) with the Speckled Sandstone group, though in his table he still placed it at the base of the middle Productus limestone, where Noetling likewise placed it. The present practice of the Indian Survey seems to be the reference of the Katta together with the Amb beds, to the Lower Productus limestone (Waagen's Upper Speckled sandstone).

The Glacial Tillites: The Pendschab group, or Speckled sandstone group proper, begins with the boulder bed of the Talchir formation, which rests unconformably upon Cambrian beds and is

succeeded by sandstones with marine fossils. This is widely distributed in India, occurring not only in the Salt Range, but also in Rajputana, Orissa and elsewhere, and has been reported from Siam. It is typical tillite or ancient consolidated boulder clay, resting upon a rock surface which is often striated and planed off, and shows characters similar to the surfaces on which the Pleistocene glacial beds of the western hemisphere rest. Striated boulders, transported for some distance, are a characteristic feature of the late Palæozoic, as of the Pleistocene glacial deposits. "Many of the boulders in the boulder bed of the Salt Range are striated and polished blocks of Malani rhyolites of Vindhyan age (Pre-Cambrian—Sinian System), an important formation of Rajputana. These are intermixed with smaller pebbles from various other crystalline rocks of the same area, and embedded in a fine dense matrix of clay. Besides striations and polishing, a certain percentage of the pebbles and boulders shows distinct "facetting". The Aravalli region must have been the home of enormous snow fields nourishing powerful glaciers at this time, as the size of the boulders, as well as the distance to which they have been transported from their sources, clearly testify to the magnitude of the glaciers radiating from it." (Wadia, 98, pp. 139-140).

Boulder beds of similar character with ice-borne boulders of Malani rhyolites and other crystalline rocks, are found in Rajputana, in Marwar (Jodpur State) where they are known as the Bap and Pokaran beds, from characteristic localities. At the latter locality occur typical *roches moutonnées*.

Boulder beds of similar character, and undoubtedly formed during the same period of glaciation, are known from southeastern Australia (Muree glacial formation), and South Africa. In the latter region the deposit is known as the DWYKA CONGLOMERATE and it constitutes the lowest member of the continental KAROO FORMATION. It varies in thickness up to 1,000 feet or more and extends from the

Indian Ocean, between 29° and 33°30′ south latitude, northward approximately to Belfast, westward to the Vaal River, and thence in latitude 29° to within less than a hundred miles of the Atlantic, and southward to within about 150 miles of Capetown. Its former extent was apparently much greater.

"The glacial origin of the Dwyka formation" says Davis, "is as unquestionable as is that of the drift sheets of northeastern America or of northwestern Europe, but the Permian ice-sheet, by which the Dwyka was formed, moved in general *southward* from the region of the equator to the region of the pole" (Davis 12a p. 401). The indications are that the Dwyka ice "was a broad and continuous ice-sheet, which spread across about 600 miles of country, east and west, and which advanced at least 500 miles poleward from its apparent source. It moved across a region which bore subdued mountains here and there, but which was reduced to moderate relief by previous erosion over large areas." (Davis 12a, p. 413).

In India the movement of the ice was in general northward or away from the equator, except locally where influenced by the topography. Farther north no evidence of glacial conditions at this period is known. In North China, this was a period of erosion followed by mixed marine and continental sedimentation (SHANSI SERIES) with coals, and later by fluviatile argillaceous marls and thin sandstones and coals (LOWER SHIHHIOTZE SERIES). These are succeeded by lateritic deposits, indicating a hot humid climate similar to the present climate of parts of India and the Quaternary of Madagascar (UPPER SHIHHIOTZE SERIES). Finally there follows a deposit indicating arid climatic conditions (SHIHCHIENFENG SERIES). These formations will be more fully noted in a later part of this chapter. The Shihhotze series is of Lower Permian (Rotliegendes) age, and the Shansi series, which contains a normal temperate marine fauna, is of Permo-Carboniferous age, to which period the Talchir of India is

referred, though it may be somewhat older. In any case, north China was not subject to glacial conditions, but was probably a region of temperate climate passing into subtropical or tropical conditions in Lower Permian time. Thus the late Palæozoic glaciation was confined to the present tropics in the old world region.

Davis has presented the facts which show that neither great elevation nor changes in land-area or landform were able to produce a glacial climate in subtropical South Africa, or India, nor could any conceivable arrangement of ocean currents produce it. General refrigeration alone, either by a decrease of solar radiation or by a change in the constitution of our atmosphere, without shifting of wind belts, would have to be so extreme as to reduce the summer temperature of South Africa and India to such an extent that the summer rains would become summer snows, while the winters would still be dry and extremely cold. Such a refrigeration would freeze up all the temperate lands of the globe and would certainly not permit the conditions which then existed in north China and the development there, in Lower Permian time, of a subtropical climate.

In the present state of our knowledge the only satisfactory theory to account for these anomalous conditions is that which postulates a shifting of the poles of the earth, with an accompanying shifting of the temperature zones, and the belts of prevailing winds. If one of the poles of the earth were situated at that time, in the region of the Indian Ocean, the observed conditions of glaciation might probably be accounted for. This problem has been discussed at some length by Koken (57) with especial reference to India, and he gives a map of the world showing the possible position of the poles at that time in conformity with this theory. He places the North Pole near Tulterango Mexico (Lat. 20° N., Long., 100° W. of today) and the South Pole in the middle of the Indian Ocean (Lat. 20° S., Long. 80° E. of today).

There is abundant evidence throughout the Palæozoic deposits, to indicate that the prevailing wind belts, and hence the polar positions, were different from what they are today, but it is not indicated so far whether they were in essentially the same position throughout Palæozoic time or whether there was a shifting from period to period. As we have seen, the present North polar region was the center of coral growth and distribution in Palæozoic time, and it now appears that certain portions of the present tropics were centers of glacial distribution, at least during the later Palæozoic periods.

The Speckled Sandstone or Pendschab Series: The boulder bed of the Salt Range is succeeded by beds of olive-green sandstone (Dandote group) which enclose two marine zones, that of *Eurydesma globosa* below, and that of *Conularia laevigata* above. The fossils of this formation are similar to those of the Permo-Carboniferous of Australia, and in both regions mark the return of the sea after the glacial conditions had disappeared, though this may have been after an interval of non-deposition of greater or less duration. This marine invasion was, however, temporary, for the succeeding mottled or "Speckled" cross-bedded sandstones, 300 to 500 feet in thickness, and inter-bedded with red shales, mark a return of continental conditions.

The Lower Productus Limestones. The succeeding series, designated the Lower Productus limestone, consists nevertheless mostly of soft calcareous sandstones full of fossils, and with coal-partings in the lower part. The lower division, which is chiefly sands, is known as the Amb series, while the upper, a crinoidal limestone, forms the Katta beds. The fauna of this entire series is markedly distinct from that of the underlying Pendschab series. It is especially characterized by numerous *Producti*, of which *P. cora*, *P. lineatus*, *P. semireticulatus*, and *P. spiralis* are leading forms. These are wide-ranging types, but suggest a Carboniferous rather than a Permian

age. Other characteristic species are *Spirifer marcoui* Waagen (Fig. 182, p. 268), *Chonetes ambiensis* Waag., *Aulosteges medlicottianus* Waag., *Marginifera ovalis* Waag., *Richthofenia lawrenciana* Waag. (Fig. 252), and *Hemiptychina sublævis*. The Amb group is further especially characterized by the great abundance of *Aulosteges* and *Marginifera*, as well as the abundant occurrence of *Fusulina*, and the absence of ammonoids. Palæontologically it constitutes the zone of *Spirifer marcoui*.

The KATTA BED or Zone of *Fusulina kattaensis* is referred to the top of the lower Productus limestone, rather than to the base of the middle, where Noetling placed it. It consists of dark platey limestones of no great thickness, without ammonites, but with abundant *Fusulinæ*.

On the whole, this fauna is quite distinct from that of the middle Productus limestone, and it is not unlikely that these two divisions are separated by a hiatus and disconformity. In that case the lower Productus limestone is probably of Uralian age, and may indeed represent the Gschellian horizon of Russia, as held by Tschernyschew.

THE MIDDLE PRODUCTUS LIMESTONE. The middle Productus limestone is the thickest and most characteristic member of the series, and consists mainly of blue or gray limestones, which are important cliff-formers in the Salt Range. With these limestones occur frequently white or cream-colored dolomite layers and marls, the latter furnishing most of the fossils. Many fossils are silicified, and chert is common.

The number of species of fossils known from this formation is considerable, especially among the Brachiopoda. Most characteristic among these are *Lyttonia nobilis* Waag. (Fig. 240), and *Oldhamina decipiens* Waag. (Fig. 258), forms which are wide-spread in eastern Asia, but of limited vertical range, and hence eminently adapted for

correlation. Among other characteristic species may be noted *Camarophoria purdoni* Dav., *Uncinulus timorensis* Beyr., *Notothyris inflata* Waag., *N. subvesicularis* Waag., *Hemiptychina himalayensis* Dav., *Entelctes latesinuata* Waag., *Eumetria grandicosta* (Dav.), *Spirigerella derbyi* Waag., *Athyris royssi* l'Ev , *A. globulina* Waag., *A. subexpansa* Waag., *Spirifer wynnii* Waag. (Fig. 279), *S. musakheilensis* Dav., *S. alatus* Schloth., *Spiriferina cristata* Schloth., *Derbya grandis* Waag., *D. verchcrii* Waag., *Streptorhynchus pectiniformis* Dav. (Fig. 257), *Productus lineatus* Waag , *P. spiralis* Waag., *P. indicus* Waag., *P. gratiosus* Waag., *P. tumidus* Waag., *P. abichi* Waag. (Fig. 238), *P. serialis* Waag., *P. opuntia* Waag., *Chonetes semiovalis* Waag., *C. grandicosta* Waag., *Chonetella nasuta* Waag., *Marginifera typica* Waag., and *Richthofenia lawrenciana* Waag. (Fig. 252).

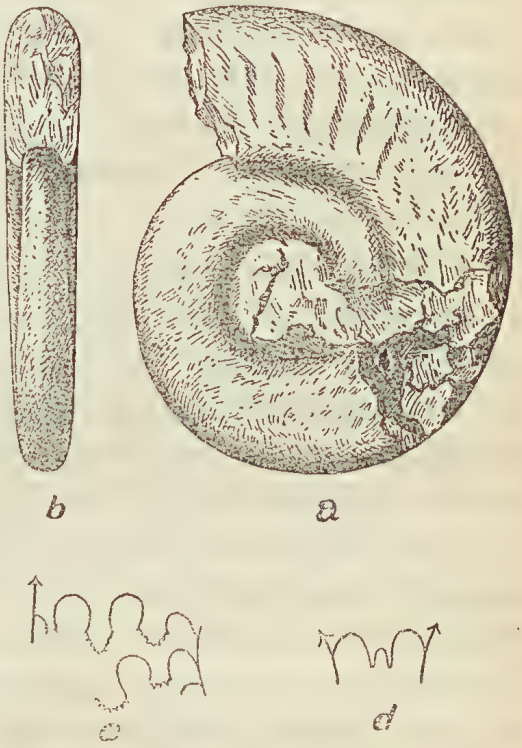

Fig. 334.

Xenaspis carbonaria Waagen *a-b.* medium sized shell; *c.* septal suture ×1½ *d.* internal suture ×1½.

Characteristic bryozoans are: *Fenestella perelegans* Meek, *Polypora koninckiana* Waag., and *P. gigantea* Waagen. Corals are characteristic, these including *Lonsdaleia salinaria* Waag. (Figs. 237a, b.), *Michelinia indica* Waag., *Dybowskiella grandis* Waag., *Aracopora ramosa* Waag., *Hexagonella ramosa* Waag., and *Amblysiphonella vesiculosa* de Kon. In the highest beds occurs the

only ceratitic ammonoid, namely *Xenodiscus* (*Xenaspis*) *carbonarius* Waag. (Fig. 334), which is abundant there.

The Upper Productus Limestone. The upper Productus limestone is again a prevailingly arenaceous series, consisting of sandstones with carbonaceous shales, and with subordinate beds of limestone and dolomite. Yellow and rusty-brown colors prevail. Fossils are abundant, most noteworthy among them being the early ammonoids, which are chiefly found in the upper or Chideru beds, where they are associated with numerous pelecypods but few brachiopods. The latter are more characteristic of the lower members of this series.

The cephalopods include the following forms: *Medlicottia wynnii* Waagen (Fig. 233), *Cyclolobus oldhami* Waag., and *Popanoceras priscum* (Waagen). The gastropods are principally represented by Bellerophontids, including *Bellerophon impressus* Waag., *B. jonesianus* de Kon., *B. affinis* Waag., *Euphemus indicus* Waag., and *Bucania ornatissima* Waag. The pelecypods belong to the genera *Myophoria*, *Schizodus*, *Lucina*, etc. The characteristic brachiopods include: *Derbya hemisphærica* Waag., *Strophalosia indica* Waag., *Productus purdoni* de Kon., *P. indicus* Waag., *P. lineatus* Waag., *P. abichi* Waag. (Fig. 258), *P. serialis* Waag., *Spiriferella grandis* Dav., and *Oldhamina decipiens* de Kon. (Fig. 258). In the upper beds the bryozoan (?) *Entalis herculea* de Kon. is extremely abundant.

The Permian Elsewhere in Western and Central Asia.

Asia Minor. As we have seen in the preceding chapter, Fusulina limestone is well developed in southern and western Asia Minor but there is a difference of opinion as to whether this is to be classed as Upper Carboniferous or Lower Permian; Dyhrenfurth has placed most of them into the Permian. At Balia-Maden a continuous section, including Upper Carboniferous and Lower Permian, has been

found. In the nothern part where, as at Eregli, the Upper Carboniferous is represented by continental sediments, it is followed by red sandstones, shales and conglomerates, which have been classified as Rotliegendes or Lower continental Permian. From near Amasia, some plant remains have been reported which indicate the continental phase of the Lower Rotliegendes.

Djulfa Section and Persia. About eight kilometers west of Djulfa, on the Araxes River, and upon the Russian border, lies a series of marly limestone which contains a fauna representing an intermediate phase between the European and Indian late Palæozoic. These beds, called the *Djulfa beds*, have been regarded as representing the Lower Neo-dyas, or approximately Middle Permian, comparable to the lower Zechstein of Europe or the higher Productus limestones of India. The fauna consists largely of brachiopods and mollusks, especially cephalopods, of which more than half the number appear to be peculiar to the Permian. Of the widely distributed species, the majority are closely related to, or identical with, those of the Upper Productus limestone of India, while the relationship to the Russian and German Permian (Zechstein) is more remote; similar beds are found in the Elburz mountains. In central Persia beds of Permo-Carboniferous age are found at the village of Soh, in the Kohrud mountains. They contain a remarkable fauna, some species of which if correctly identified, are of Devonian habitus. The following is a partial list of those recorded: *Waldheimia whidbornii*, *Rhynchonella elliptica* Schnur., (Calceola beds of the Eifel) *Regina semiramis*, *Nyassa dorsata* Gf., *Spiriferina cristata* Schl. (Productus limestone of India), *Eumetria indica* Waag, *Athyris* cf. *roissyi* Leviller, *Athyris* cf. *lamellosa*, *Terebratula vesicularis* and others. In western Persia, beds similar to those of the Indian Salt Range have been found in the Kaliankuh, in the Bachtiary district. They consist of black and gray limestones containing: *Pseudophillipsia* cf. *elegans* Gemmellaro,

Nautilus cf. *tuberculatis* Abich, *Bellerophon* cf. *squamatus* Waag., *Murchisonia conjungens* Waag., *Productus striatus* Fischer, *Orthothetes crenistria* Phill , *Streptorhynchus* cf. *pelargonatus*, *Productus helicus* Abich, *Spirifer lineatus* Mart., *Spirigerella grandis* Davies, *Michelinia*, *Lonsdaleia*, etc.

Turkestan and Sinkiang. In east Bokhara, the Upper Carboniferous is followed conformably by a great series of marly and sandy-calcareous sediments with alternating beds of tuffs, frequently with fusulinas and with conglomerates, sandstones and clays, with slate and gypsum predominating in the upper part. The highest members are sandstones with mullusks, brachiopods and bryozoans: *Myophoria darvasana*, *Clidophorus* sp., *Avicula* sp., *Martinia kraffti*?, *Spirigera*. An impression of a ceratite referable to *Medlicottia* or *Propinacoceras* was found in a pebble in the Tertiary conglomerates.

The lower division of the Permian has been found to contain a rich fauna of fusulinas, bryozoans, corals, cephalopods and brachiopods including on the Obi-Rawnou river, Darwas, the following: *Dielasma elongatum*, *Hemiptychina darvasica*, *Lyttonia nobilis*, *Athyris protea* var. *alata*, *Ambocoelia telleri*, *Enteletes elegans*, *Orthotichia morgani*, *Productus* cf *gratiosus*, *P. aculeatus*, *P. lineatus*, *Aulosteges* aff. *medlicotti*, *Clinopistha radiata*, *Schizodus wheeleri*, *Bakewellia cerathophaga*, *Pecten edelsteini*, etc. The Permian beds are in turn succeeded concordantly by Triassic strata of Scythian age, and it seems that the Permian is fully developed in this region.

It is not improbable that some of the limestones referred to the Upper Carboniferous in the western Kwenlun, represent in reality Lower Permian or Permo-Carboniferous. This appears to be the case with the limestones found in the Tisnab basin on the left bank of the Gussass river. These too, lie unconformably upon folded Moscovian sediments and contain the following species: *Productus* ? *tibeticus*, *Orthis* cf. *indica*, *Athyris* sp., *Streptorhynchus difficilis*, *Martinia*

planoconvexa, *Bellerophon* sp. Beds perhaps of similar age, are found in the border region between the Tianshan and the Alai at Alaiku. They rest unconformably upon the Lower Carboniferous and consist of shales, sandstones, breccias and conglomerates. In the shales impression of *Helicoprion*? have been found.

Between the western Kwenlun and the Karakorum ranges, the Triassic sediments are found locally to rest upon limestones which

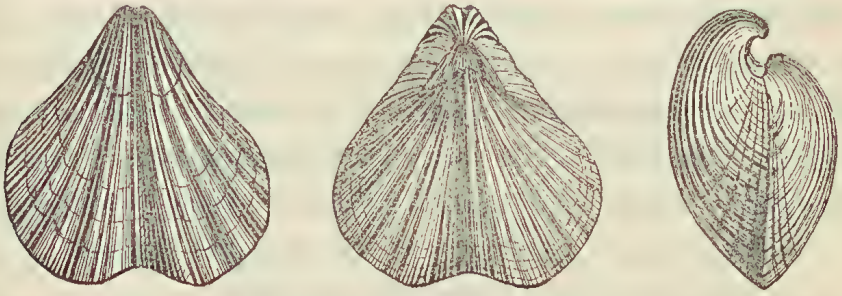

Fig. 335. *Spirifer tibetanus.*

in some cases, contain Permian fossils, as at Woabdschilga, where the following have been found: *Xenodiscus peregrinus* or *carbonarius*, *Gastrioceras abichianum*,? *Orthoceras* sp., *Nautilus convolutus*? This fauna appears to be of the age of the Djulfa beds of Armenia. In the south-eastern and southern part of the middle Kwenlun, Permian beds have been recognized at several localities. At one of these, west of Lant-choufu, on the Tatungho, these beds are developed in brackish facies consisting of alternating sandstones and shales with trails of worms, carbonized plant remains and impressions of *Allorisma* cf. *perelegans*.

Siberia and Mongolia: Continental Permian beds are found in the Altai region and the Kusnezk basin of Siberia, the flora of these beds already including species of Mesozoic affinity. They are described more fully below. These beds are succeeded by the continental Angara series. Marine Permian beds, on the other hand, were deposited in the Mongolian geosyncline where in latitude 44° 43′

N., and between longitudes 107° 30′ and 108° E., Professors Berkey and Morris, of the Third Asiatic Expedition, discovered strata with *Lyttonia* and other Permian fossils. This water-body continued eastward to the Pacific where, as will be shown later, marine beds of this age occur in the vicinity of Vladivostok and elsewhere.

During the second season's field work in Mongolia, Professor Morris made an extensive collection of fossils from the *Lyttonia* beds at Jisu-Honguer which is definitely located in Lat. 42° 18′ N., Long. 109° 43′ E. Among the most characteristic fossils of these beds is a great series of mutations of *Spirifer rahja* while *S. tibetanus* (Fig. 333), is also present.* This formation appears to lie directly upon older rocks overlapping the Dinantian of Sair-Usu.

Himalayan Geosyncline. This important water-way was the site of extensive marine deposition in Middle and Upper Permian time, and formed the main line of communication between the basin of China and the European region, though a broad connection with the Indian Ocean existed on the south (See Map, Fig. 229). The central Asiatic area, which joined it to the Mongolian geosyncline, was a part of this essentially Asiatic Permian or Indo-Pacific region, which opened on the one hand into the Mediterranean basin on the west, and on the other to the Russian basin on the north. The latter connection was probably intermittent, and on the whole not very effective, this being indicated by the essential distinctness of the faunas of the two regions. The connection with the Mediterranean, though more effective, was probably also at times incomplete, so that in the two regions there were developed essentially distinct faunas.

The typical succession shown in the Salt Range of Western India has already been described (p. 328). This probably lay nearer the southern margin of the geosynclinal area, though well away from

* These fossils are now being studied in the Survey Laboratories.

the coast, permitting an extensive development of calcareous beds. We shall next note the development of this system in Kashmir on the north, and then consider some of the typical known occurrences in the region of the modern Himalaya Mountains.

Kashmir. As has been shown in the preceding chapter (p. 287) the Panjal volcanic series is followed by novaculites and siliceous shales which include a Lower Gondwana flora with *Gangamopteris* (*G. indica*) and other plants, indicating the horizon of the Talchir series of the Indian Peninsula. At Zéwan, in the Vihi district of Kashmir, these beds are succeeded by fossiliferous shales and limestones of Permian age, constituting the ZEWAN SERIES. The following section gives a summary of this series.

SUPER-FORMATION *Meekoceras beds* of the Lower Triassic

Hiatus and Disconformity (See Chapter X)

ZÉWAN SERIES:

4. *Xenaspis carbonaria zone.* Shales and thin-bedded limestones ..... 100 ft.
3. *Marginifera himalayensis zone.* Dark arenaceous shales, micaceous and carbonaceous, with limestone intercalations at the base..... 300 ft.
2. *Protoretepora zone.* Shales and limestones..... 30 ft.
1. *Hemiptychina zone.* Dark gray limestones with shale partings..... 60 ft.

SUB-FORMATION: Gangamopteris beds.

The lowest, or HEMIPTYCHINA ZONE, is characterized by the following brachiopod fauna: *Productus cora* d'Orb., *P. purdoni* Dav., *P. gangeticus* Diener, *Marginifera spinocostata* Ab., *Spirifer fasciger* Keys., *Spirigerella* (*Athyris*) *derbyi* Waag., *Camarophoria purdoni* Dav., and *Hemiptychina himalayensis* Dav.

The PROTORETEPORA ZONE abounds in this characteristic bryozoan, which is however, not wholly restricted to it. The fauna is rich in individuals though poor in species. The following have been identified: *Lyttonia nobilis* Waag., **Spiriferina zewanensis* Dien., *Derbya?* sp. and *Protoretepora ampla* Lonsd.

The third zone, with *Marginifera himalayensis* is divisible into three subzones. The lowest, comprising mostly limestones, is the subzone of *Productus indicus* and is chiefly characterized by the predominance of *Producti* belonging to the section of *semireticulati*. The fauna includes the following species: *Aviculopecten* cf. *hiemalis* Salt., *Productus indicus* Waag., *P. spiralis* Waag., *P. gratiosus* Waag., *P. abichi* Waag. (Fig. 238), *P. gangeticus* Dien., *P. cancrini* Vern., *P.* cf. *cancriniformis* Tschern. (Fig. 222), *Marginifera himalayensis* Dien., *M. vihiana* Dien., *Spirifer rajah* Dien., *Spiriferina cristata* var. *fastigata* Schellw., *S.* cf. *vercherii* Waag., **Spirigera xetra* Dien., *S. royssii* Lev., *S. subexpansa* Waag., *Camarophoria purdoni* Dav., *Dielasma biplex* Waag., *D. acutangulum* Dien., *Hemiptychina himalayensis* Dien.

The main Marginifera sub-zone is characterized by the following fauna **Eumicrotis middlemissi* Dien., **Productus waagenianus* Girty, *P. abichi* Waag. (Fig. 238), *P. gangeticus* Dien., *Marginifera himalayensis* Dien., *Chonetes lissarensis* Dien., *Lyttonia nobilis* Waag., *Spirifer fasciger* Keys., *S. nitiensis* Dien., *S. rajah* Salt., *Spiriferina cristata* var. *fastigata* Schellw., *S. ornata* Waag., **S. zewanensis* Dien., *Spirigera* cf. *gerardi* Dien., *S. subexpansa* Waag., *Camarophoria purdoni* Dav., and *Dielasma latouchii* Dien. The three leading species of this zone are *Productus waagenianus*, *Marginifera himalayensis* and *Spirifer rajah*.

The chief character of this subzone is the absence of *Producti* of the *semireticulatus* section, but otherwise they are intimately connected palæontologically as well as stratigraphically.

The third subzone is that of *Spirifer rajah*. This species predominates, though it is by no means restricted to it. The fauna of this zone includes: *Productus* aff. *cancrini* Vern., *P. abichi* Waag., *P. gangeticus* Dien , *Chonetes* cf. *vishnu* Salt., *Spirifer fasciger* Keys., *S. rajah* Salt.

The highest zone, or that of *Xenaspis carbonaria* is quite distinct from those underlying it, being characterized in addition to the zone fossil, by many pelecypods of the genera *Eumycrotis*, *Pseudomonotis*, *Aviculopecten*, *Pleurophorus* and *Schizodus*. Brachiopods are also abundant in some sections including the following species: *Productus* cf. *purdoni* Dav., *P. indicus?* Waag., *P. spiralis* Waag., *P. abichi* Waag., *P. gangeticus* Dien., **P. waagenianus* Girty, *Marginifera himalayensis* Dien., *M.* cf. *helica* Ab., and *Chonetes lissarensis* Diener.

One of the noteworthy facts is the entire absence of Fusulinæ in the Permian beds of the Himalayas, though they are found in the Salt Range, in Afghanistan, and in Burma. Corals are rare, but crinoids are well represented by their stem joints. Among the brachiopods *Productus waagenianus* Girty is noteworthy, as that was originally described from the Guadaloupian Permian of Texas, thus showing trans-Pacific faunal migration, probably by way of the Mongolian geosyncline and the present north Pacific coastal region.

With slight exceptions (those marked by an asterisks*) all the species listed above are also found in the Kuling shales and Chitichun limestone of the Central Himalayas and in the Productus limestone of the Salt Range. Among the exceptions are *Productus waagenianus* Girty and *Marginifera spinocostata* Ab., characteristic Permian species, the first of Texas, the second of western Asia.

Spiti Region. The most complete development of the later Palæozoic beds known in the Himalaya Mountains is that found exposed in Spiti, in the northwestern portion of that range, and near

the Tibetan border. In the vicinity of Muth and elsewhere, white quartzites about 500 feet thick, and probably of pre-Carboniferous age, are overlain by a few hundred feet of gray flaggy limestone. This in turn is followed by the KULING shales, a great series of sandstones and shales which have yielded a fauna of Permian age, and are the equivalent of the PRODUCTUS SHALES of the central Himalayas. Between the Kuling shale and the flaggy limestone is a pronounced disconformity, the higher series beginning with a thin bed of conglomerate. In other sections an extensive series of grits and conglomerates (PO SERIES) underlies the Kuling shales disconformably and passes down into several alternating shales and quartzites. In the lower Spiti valley, this series is at least 3,000 feet thick the limestone and Muth quartzite not being exposed, but in the Lipak river, above Lio, both the Muth quartzite and the gray limestone (LIPAK SERIES) are present, the thickness of the entire succession, from the base of the Muth quartzite to the disconformity at the base of the Kuling (*Productus*) shales, being not less than 5,000 feet.

In the beds of the PO SERIES overlying the gray limestone (Lipak Series) three fossiliferous horizons have been discovered, situated at about 500, 1,000, and 1,500 feet respectively, below the Kuling beds. The upper two have been called *Fenestella beds* on account of the abundance of Bryozoa. The lowest (Thabo) fossil horizon consists of dark gray and black shales and contains many plant remains of the Culm type.

The age of the white Muth quartzite is indeterminate. The flaggy limestone above it has yielded a small fauna which includes *Syringothyris cuspidata*. This is the Lipak series of Dinantian age (see p. 235). A richer fauna has been obtained from equivalent beds in Kanaur, where the series is typically developed.

The plant remains of the next fossil horizon, the lowest of the Po Series, are indeterminable, but the upper fossil beds or *Fenes-*

tella beds have yielded a small fauna, of which the following have been definitely identified: *Productus undatus* Defr., *P. scabriculus* Mart., and var. *spitiensis* Diener., *P. nystianus* var. *lopingensis* Kayser, *Protoretepora ampla* Lonsd. The occurrence of *Productus nystianus* var. *lopingensis*, a form originally described from the Loping beds of China, suggests Permian age, but it is probable that this form (if correctly identified) may have a much longer range, and that the series is more probably of early Uralian (Gschellian), if not of Moscovian age. As before noted the horizon is probably not younger than the lower Productus limestone or Amb series, and may be somewhat older. If a disconformity really exists between the Amb series and the middle Productus limestone, as seems to be the case, it is probably the same disconformity which separates these lower beds from the Kuling shales. The Po Series, like the Fenestella shales of the Kashmir region, was deposited during the period of contracted seas following the Taiyuan expansion, and represented a local or provincial faunal unit. (see *ante*, p. 289.)

The KULING SERIES is divisible into three parts as follows; in descending order:

C. Black shales with limestone partings (Productus shales, or Kuling Shales proper.)

B. Calcareous sandstones.

A. Unfossiliferous grits and conglomerates.

Disconformity.

Lower Series.

The black Kuling shale is succeeded by the *Otoceras* beds of the Triassic, there being probably a hiatus between, though, according to Noetling and Diener, there is no break in successions.* In Kashmir the Zéwan beds form its equivalent.

* See the discussions of this question in Chapter X.

The Kuling shale is correlated with the Upper Productus limestone or Chideru group (Noetling) of the Salt Range, and the Calcareous sandstone (B) with the Middle Productus limestone or Virgal group (Noetling). The basal beds (A) are probably to be classed with the lower part of the group. Thus the disconformity which separates this upper from the lower series falls at the base of the Virgal group, where, as before suggested, there is probably the same disconformity separating the Middle and Lower Productus limestones.

From the calcareous sandstone (B) has been obtained a fauna rich in numbers, though rather poor in species. The forms definitely identified include: PELECYPODS: 1 *Oxytoma laticostatum* Nitsch., BRACHIOPODS: 2 *Spirifer fasciger* Keyser. 3 *S. nitiensis* Dien., 4 *S. distefanii* Gemm., 5 *S. marcoui* Waag., 6 *Spirigera gerardi* Dien., 7 *Diclasma latouchii* Dien., 8 *Aulosteges* cf. *gigas* Nitsch. Numbers 1, 2, and 6 are also found in the Kuling shales, and numbers 1, 4 and 8 are European Permian species.

The Kuling shale has a fauna more numerous in species of which two, *Marginifera himalayensis* Dien., and *Spirifer rajah* Salt., including such mutations as *S. tibetanus* (Fig. 235), are the most abundant and characteristic, as well as the most widely distributed forms. Two ammonoid genera *Cyclololus* (*C. insignis* Dien., *C. kraffti* Dien., *C. haydeni* Dien., *C.* cf. *oldhami* Waag.), and *Xenaspis* (*X.* cf. *carbonaria* Waag.), point strongly to an equivalency with the Upper Productus limestone, and the other fossils do not negative this correlation. Other characteristic species are: *Chonetes lissarensis* Dien., *Myophoria kraffti*, *Modiolopsis teplofi* Vern., *Solemya biamica* Vern., etc.

These shales and calcareous sandstones should probably be considered the nearer shore deposits of the Permian series in the Himalayan geosyncline, their more open water equivalents being the

Productus Limestone of the Salt Range. The Kuling shale is represented in the Central Himalayas by the Productus shales of Johar and Painkhanda, the Lyssar Valley, and Byans. In the Niti district, the Productus shales may represent both the Middle and Upper Productus limestone.

Chitichun: The limestone facies is again met with north of the main belt of sedimentation in the Central Himalayas in the peak known as Chitichun No. 1, in the Hundes district of Tibet, between the Leptal range and the head of the Dharma valley. The rock is a white, partly semicrystalline limestone, alternating with layers of red, arenaceous, or earthy limestone and with lenticular intercalations of a red crinoidal limestone. The series is from 300 to 450 feet in thickness and apparently rests on Spiti shale (Barriasian stage of the Lower Cretaceous) probably as the result of thrust faulting. The fauna is a rich one, forty-eight species having been recorded by Diener (15). Brachiopods predominate with forty species, including such characteristic forms as *Productus lineatus* Waag., *P. cora* d'Orb., *P. semireticulatus* Mart., *P. cancriniformis* Tschern. (Fig. 222), *P. abichi* Waag. (Fig. 238), *P. mongolicus* Dien., *Marginifera typica* Waag., *Aulosteges tibeticus* Dien., *Lyttonia nobilis* Waag. (Fig. 240), *Spirifer musakheylensis* Davids., *S. wynnii* Waag. (Fig. 278), *S. tibetanus* Diener (Fig. 335), *Martinia elegans* Dien., *M. nucula* Rothpl., *M. semiplana* Waag. (Fig. 251), *M. acutomarginalis* Diener, *M. contracta* Meek and Worthen, *Reticularia lineata* Mart., *Athyris* (*Spirigera*) *royssi* l'Ev., *A. subexpansus* Waag., *Spirigerella derbyi* Waag., *S. grandis* Waag., *Enteletes tschernycheffi* Diener, *Uncinulus timorensis* Beyr., *Camarophoria purdoni* Dav., *C. gigantea* Diener, *Hemiptychina himalayensis* Dav., *H. sparsiplicata* Waag., *H. inflata* Waag., *Dielasma biplex* Waag., and *Nothothyris triplicata* Diener. Of cephalopods Diener records *Stacheoceras trimurti* Dien., and of tribobites, *Phillipsia middlemissi* Dien., and *Cheiropyge himalayensis*

Diener. The fauna shows that this limestone corresponds to the upper part of the Middle Productus limestone, being apparently deposited in the same basin.

Compared with western Europe, these limestones are most probably to be placed above the Sosio limestone of Sicily, probably corresponding more nearly to the age of the Bellerophon limestone, though that is a marginal, and in part lagoonal deposit, and therefore has a distinctive fauna. The occurrence in that limestone, however, of the characteristic Asiatic coral *Lonsdaleia indica* (Fig. 336), furnishes a strong argument in support of this correlation. As we shall see presently, these horizons are represented in China by deposits formed during the same period of marine transgression, and in general continuous with those of the Himalayan geosyncline.

Burma In the Shan States of Burma the crystalline dolomites with the *Calceola* fauna (Eifelian division of the Devonian), are followed disconformably by the Upper Plateau limestone. This is partly dolomitic and brecciated and in the main unfossiliferous. It is succeeded disconformably by the Napeng beds of Rhætic age. The lower part of the Plateau limestone may be of Dinantian age, but in the upper part fossils of Permian age have been found, corresponding to those of the Salt Range and the Himalayas above noted.

Fossils have been obtained from four localities (Diener 19): (1) In the Southern Shan States certain bands of shaly limestones and marls, in the hills between Hopong and Mongpawn, have yielded fossils of the age of the Middle Productus limestone of the Salt Range. In the northern Shan States fossils have been found on the limestone plateau at (2) Namun (Lat. 22° 18′ N., Long. 97° 41′ E.) where shaly limestone yielded numerous *Fenestellæ* and brachiopods of the same age; (3) near Tonbo, east of Mandalay, where *Fusulinæ* also abound; and (4) near Kehsi Mansam, where *Fusulinæ*, brachiopods and corals occur. The faunas of the first two and the last localities

suggest in a general way the same stratigraphic horizon, which is that of the Middle and Upper Productus limestone of the Salt Range. Out of 47 forms, which are specifically determinable, the following 30 (about 64%) are identical with, or closely allied to, Salt Range species. (A. Möngpawn, B. Namun, C. Kehsi Mansam.)

		A	B	C
ANTHOZOA				
1.	*Lonsdaleia indica* Waag. & Wentz. (Fig. 236)	...	...	×
BRYOZOA				
2.	*Hexagonella ramosa* Waag.	...	×	...
3.	*Geinitziella* cf. *columnaris* Schloth.	...	×	...
4.	*Fenestella* cf. *perelegans* Meek	...	×	...
5.	*Polypora* cf. *ornata* Waag.	...	×	...
6.	*P.* cf. *biarmica* Keyserl.	...	×	...
7.	*P.* cf. *megastoma* de Kon.	...	×	...
BRACHIOPODA				
8.	*Spirifer fasciger* Keyserl.	×	×	×
9.	*S. striatus* Mart.	...	×	×
10.	*Reticularia* cf. *lineata* Mart.	...	...	×
11.	*Spiriferina cristata* Schloth.	...	×	×
12.	*Spirigera royssi* L'Ev.	×	...	×
13.	*Spirigerella derbyi* Waag.	×	...	×
14.	*Hustedia remota* Eichw.	..	...	×
15.	*Streptorhynchus* cf. *semiplanus* Waag.	...	×	...
16.	*Schizophoria indica* Waag.	×	×	×
17.	*Oldhamina* cf. *decipiens* de Kon. (Fig. 258)	...	...	×
18.	*Productus cora* d'Orb. (Fig. 180)	...	...	×
19.	*P. gratiosus* Waag.	....	...	×
20.	*P. abichi* Waag. (Fig. 238)	...	...	×

		A	B	C
21.	*P. cylindricus* Waag.	...	...	×
22.	*Strophalosia costata* Waag.	...	...	×
23.	*S.* cf. *indica* Waag.	...	...	×
24.	*S.* cf. *horrescens* de Vern. (Fig. 223)	...	...	×
25.	*Chonetes* cf. *squamulifera* Waag.	...	×	...
26.	*Chonetes grandicosta* Waag.	×	...	...
27.	*Dielasma biplex* Waag.	...	...	×
28.	*Notothyris simplex* Waag.	...	...	×
29.	*Camarophoria* cf. *purdoni* Dav.	...	...	×
30.	*Uncinulus timorensis* Beyr.	×	...	...

The Permian age of these beds is thus undoubted and it is clear that they belong to the same zoogeographic province as do the Indian, Mongolian and Chinese Permian formations. They are indeed a part of the deposits formed in the characteristically Asiatic *Lyttonia sea* of the Middle Permian and its successor in the Upper Permian.

Foraminifera are represented in the Burmese Permian only by *Fusulina elongata*, a form widely distributed in Asia, being known as far west as Afghanistan, and also occurring in the Texan (U.S.A.) deposits.

Corals are rare, the only species being *Lonsdaleia indica* Waag. a characteristic form of the Productus limestone, and of the equivalent beds of Indo-China. This species has also been found in the Permian Bellerophon limestone of the southern Alps, which thus appears to hold the same stratigraphic horizon. The brachiopods are chiefly of Indian types, though an important new species of strophomenoid shell, *Streptorhynchus shanensis* Diener is peculiar to this more eastern region (Kehsi Mansam). Another unique brachiopod is *Rhipidomella imitatrix*. The relationships of the *Producti* are almost equally strong

with the Upper Carboniferous of Russia, and the Productus limestone of the Salt Range, but the species with Russian affinities are chiefly such as have a wide vertical range. Among the *Chonetidæ* the most striking form is *Chonetes grandicosta*, which belongs to a group of exclusively Indian habitat.

Marine Permo-Carboniferous and Permian in China and Adjoining Districts.

Throughout north China, continental coal-bearing beds of Permo-Carboniferous age, but with marine intercalations, rest disconformably upon the Taiyuan series. These beds constitute the Shansi series, as that term has been officially restricted by the Geological Survey. No higher marine beds are found in north China, but these are known from central and south China and from Indo-China, the Malay Peninsula and Japan. They will be considered first.

SOUTH CHINA, INDO-CHINA AND THE BORDERS OF THE ASIATIC CONTINENT:

E. Yunnan. As has been noted above, the beds classed by Deprat as Upper Uralian (Zones 3 to 10 on p. 297) in eastern Yunnan, were referred by Frech to the Lower Permian. They may be the marine equivalents of the Shansi series (Permo-Carboniferous) of north China, though this is still undetermined. The Permian of Yunnan was subdivided by Deprat as follows:*

Upper Permian

7 Labradoritic rocks (eruptive)
6 Gypsiferous sands and marls
5 Heavy conglomerates
4 Calcareous beds, with *Neoschwagerina multiseptata* Deprat
3 Limestone with *Neoschwagerina globosa* Yabe, *N.* (*Suma-*

* This must be regarded as provisional and subject to revision.

trina) *annæ* Voltz, *Doliolina pseudolepida* Depr., *Schwagerina douvillii* Depr., *Fusulina exilis* Schwager, and *F. margheritii* Depr.

Middle Permian

2 Limestones with *Schwagerina verbecki* Gein. (dominant), and *Fusulina richthofeni* Schwager, *F. mansuyi* Deprat, *F. minima* Deprat, etc.

Lower Permian

1 Beds with *Spirifer blasii* Vern., *Martiniopsis inflata* Waagen, *Athyris angulata* Mans., *Spirigerella grandis* Waag., *Camarophoria globulina* Phillips, *Naticopsis spiriformis Mans.*

Sub-formation - Upper Uralian

Indo-China and Siam. While Productus limestones of the horizon of *Schwagerina princeps* are well developed in Tonking and Laos, where they constitute the so called Productus limestone of those states (Mansuy, 63,64), higher beds are less well known, though beds with *Lyttonia* are found at Hongay in the Haiphong district. (Colani 11).

In the Lang-son quadrangle, at Lang-nac, Tonking, a limestone with *Lonsdaleia indica* Waagen (Fig. 236) has been discovered indicating the Middle Productus limestone horizon, or approximately Middle Permian. What is probably the same horizon, with a fragment of a *Xenodiscus* shell, and with *Productus nystianus* var. *lopingensis* Kayser, occurs in Upper Laos, at Ban-Na-Hai, while at Hoei-Tumm-Tac beds with *Pseudomonotis gasforthensis* King, may represent this or a somewhat younger horizon.

The most complete development of limestones of Middle Permian age is however found in Cambodia (Cambodge) in southern Indo-China. The so-called Productus limestone of Cambodia, found at

Sisophon, Ta-kreem and elsewhere, is clearly that of the Middle Productus limestone of the Salt Range of India, and is younger than the Productus limestone of Tonking and Laos above noted. In addition to a large number of new species, this limestone contains the following species found in the Productus limestone of India: *Steinmannia gemina* W. & W., *Lonsdaleia salinaria* W. & W. (Fig. 237), *Geinitziella crassa* W. & W., *Productus abichi* Waagen (Fig. 238), *P. gratiosus* Waagen, *Strophalosia rarispina* Waagen, *Reticularia indica* Waagen (Fig. 239), *Notothyris warthi* Waagen mut. *cambodgiensis* Mans., and *Lyttonia nobilis* Waagen (Fig. 240).

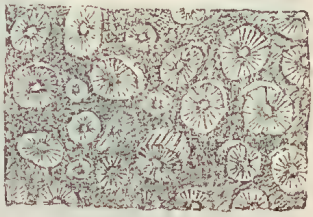

Fig. 236a.
Lonsdaleia indica W. & W. nat. size.

The highest Permian series which has been investigated in some detail is that of Luang-Prabang, in Upper Laos. Three distinctive horizons are recognized. These comprise (a) compact black limestone, very thick and containing *Neoschwagerina globosa* Yabe, *Sumatrina annæ* Voltz (Fig. 241), *Fusulina exilis* Schwager (Fig. 242), *Lonsdaleia indica* Waagen (Fig. 236), *Lyttonia* cf. *tenuis* Waag., and a number of new species. The next division (b) consists of graywackes with *Lyttonia nobilis* Waagen (Fig. 240), *Productus nystianus* de Koninck, *P. cora* d'Orb., etc.; while the highest division (c) consisting of limestones, graywackes and carbonaceous shales with plant impressions, contains *Productus nystianus* de Kon., *Modiola pallasi* de Vern., and other incompletely identified or new forms. These limestones are extensively

Fig. 236b.
Lonsdaleia indica W. & W. single corallite enlarged × 12.

developed in upper Siam, but little is known of their thickness, subdivision and fossil content. (See Högbom 51).

Malay Peninsula and East Indies. Permian limestones are again found in the Malay peninsula (at Tenasserim) and especial-

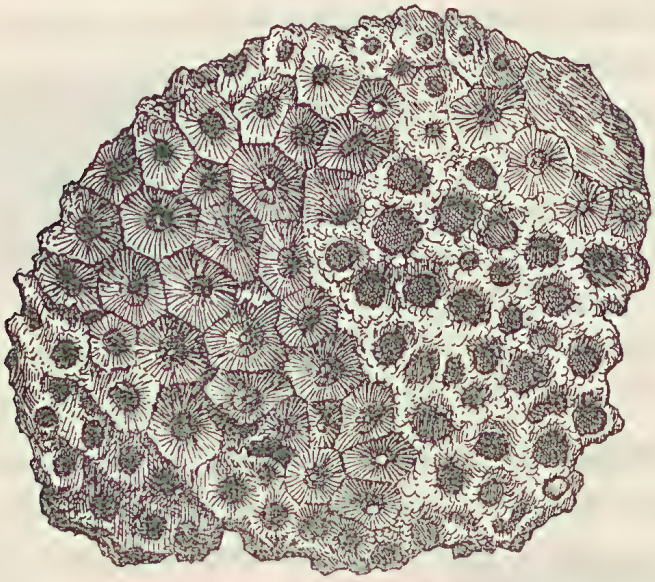

Fig. 237a. *Lonsdaleia salinaria* Waagen and Wentzel, corralum slightly reduced.

ly on Sumatra, where at Padang, on the southwest coast, two series are found, a higher with *Schwagerina verbecki*, (Fig. 243), *Neoschwagerina craticulifera*, and *Sumatriana annæ*, (Fig. 241) and rarely with *Fusulina granumavenæ*, and a lower, with *Fusulina granumavenæ*, 5 species of *Bigenerina*, *Productus sumatrensis*, *Spirifer damesi*, *Bellerophon convolutus*, *Pleurotomaria nikitini* and *Naticopsis sumatrensis*, etc. This older fauna (of some 50 species) has been described in full by Fliegel (29) who regarded is as Upper-Carboniferous, and pointed out the fact that it is an older fauna than that of Loping. Again it is a younger fauna than that of the Malay

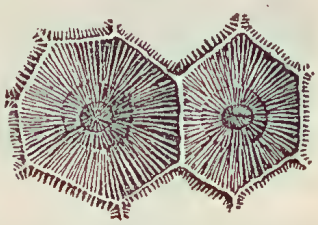

Fig. 237b.
Lonsdaleia salinaria W. & W.
Two corallites enlarged × 2.

Peninsula (Potalung, Pahang and Perak), and if not Upper Carboniferous, probably belongs to the period of the Shansi transgression (Permo-Carboniferous)

On the Island of Timor and the adjoining small island of Rotti in the Indian Archipelago, fossiliferous Permian beds are found indicating the beginning of submergence of the Cathaysian landmass in the closing stages of the Palæozoic (Rothpletz 80). The most extensive development is found on Timor,

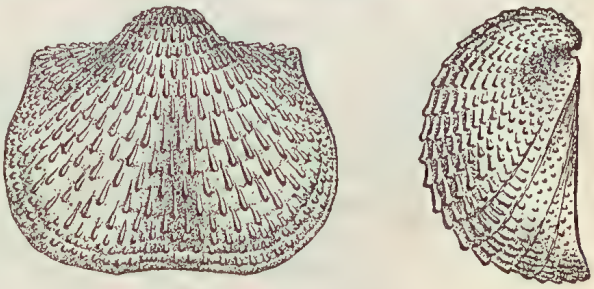

Fig. 238. *Productus abichi* Waag.

where beds of shale include a stratum of gray cherty limestone 3 to 4 meters in thickness, which contains an abundant fauna. No indication is shown as to the relationship of these beds to the underlying rocks and they are covered unconformably by nearly horizontal Tertiary beds. On Rotti, these formations have not yet been found in place but fragments of limestones thrown out in volcanic eruptions have furnished the following fossils: *Dibunophyllum australe*, *Clisiophyllum* sp., *Fenestella virgosa*, *Entrochus regularis*, and *E. irregularis*. The total number of species obtained from both Timor and Rotti is 53, of which 41 are definitely identified. 22 of these are restricted to Timor, being new species, but the other 19 are also known elsewhere and serve for correlation. Of these 19 species, 4 range from the Lower Carboniferous to the Permian,

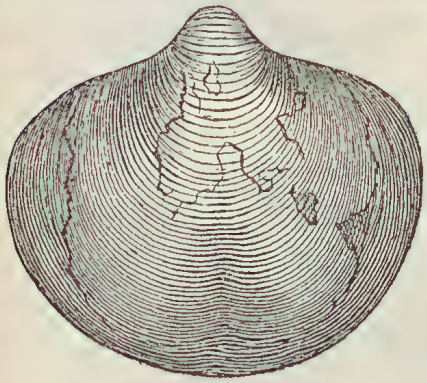

Fig. 239.
Reticularia indica Waag.

These are: *Spirigera roysi*, *Reticularia lineata*, *Spiriferina cristata* and *Productus semireticulatus*: the other 15 species, however, are more

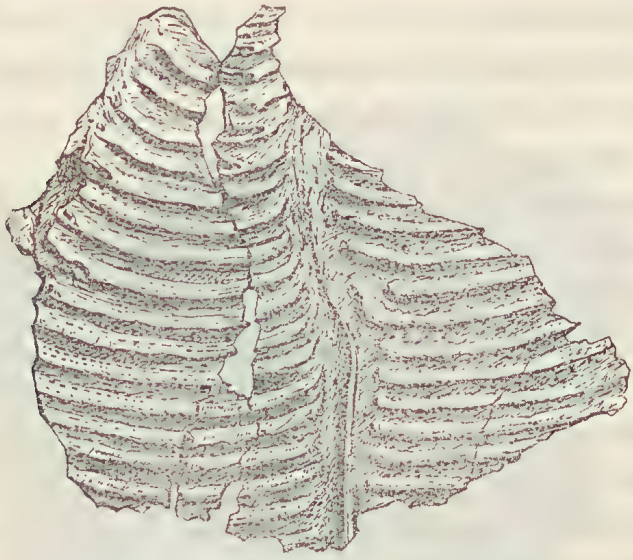

Fig. 240. *Littonia nobilis* Waag. Tonking.

definitely restricted. They are the following: *Pachypora curvata*, *Amplexus coralloides*, *Fenestella virgosa*, *Productus abichi*, *P. asperu-*

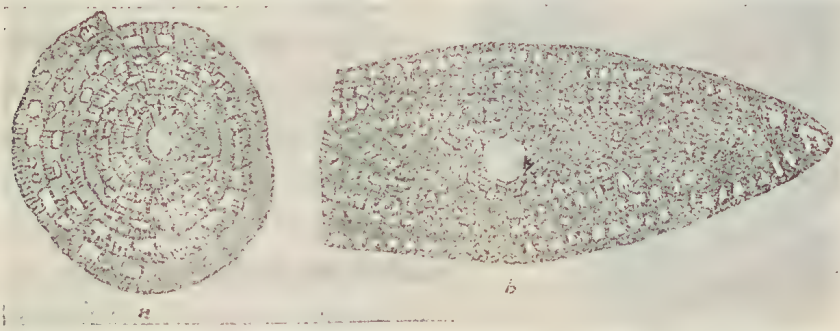

Fig. 241. *Sumatrina annæ* Voltz; *a*, median transverse section showing the longitudinal septa of the roof × 18; *b* median longitudinal section showing strong basal transverse septa (basal skeleton) and finer and more numerous transverse roof septa (secondary roof skeleton) between them × 18 (After Voltz).

lus, *P. gratiosus*, and *P. waageni*, *Chonetella nasuta*, *Spirifer musakheylensis*, *Martinia nucula*, *S. timorensis*, *Retzia grandicosta*, *Camarophoria pinguis*, *Rhynchonella timorensis*, and *Terebratula himalay-*

ensis. None of these species are known from the Carboniferous limestones of Sumatra, Australia or China but 11 have also been found in the Productus limestone of the Salt Range of India and 3 in

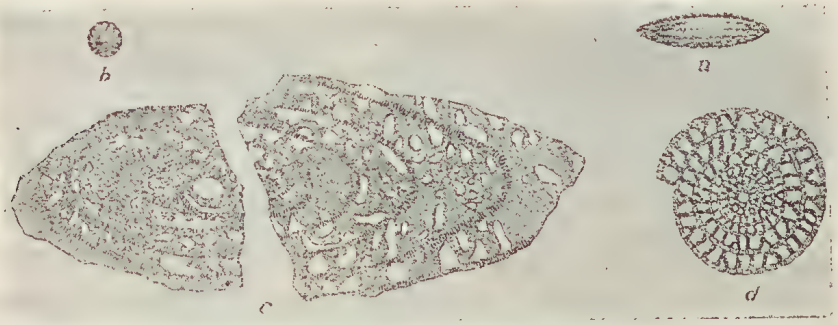

Fig. 242. *Fusulina exilis* Schwager. *a*, *b*, side and end views of entire shell × 1½; *c*, longitudinal section (of 2 separate shells but supplementary) × 10; *d*, cross-section × 5¼ (After Schellwien).

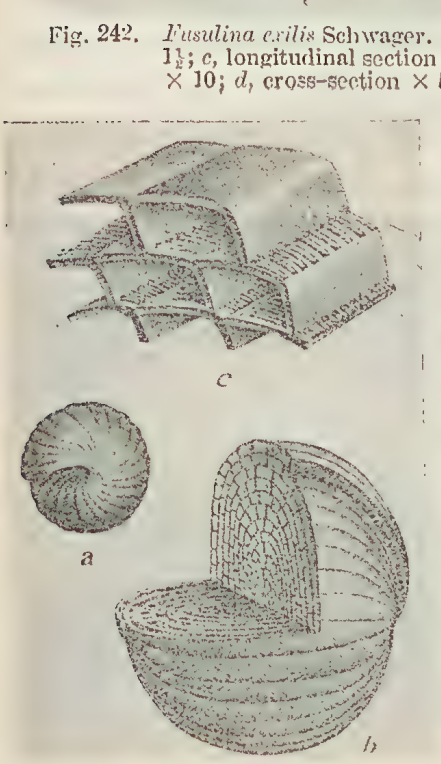

Fig. 243.

Swagerina (*Verbeckina*) *verbecki* Geinitz: *a*, end view of shell × 1½; *b*, sectioned individual × 4; *c*, diagrammatic section showing form of chambers and beginning of transverse septa or basal skeleton, which indicates transition to *Dutiolina*. Much enlarged; (After Schwager).

the Djulfa limestone (Upper Permian) of Armenia. Of the 15 species also 3 only are found in the lower Productus limestone and 11 in the middle and upper; 2 species occur in the Artinskian of Russia and 2 in the Carboniferous limestone. These, however, also occur in the Permian.

This relationship to the Permian beds of India is very significant since it clearly shows us that at this time the Himalayan geosyncline was in direct connection with the Indo-Pacific waters.

No Permian is positively known from any of the islands in the East Indian Archipelago except possibly Ambon from which island it is doubtfully reported. During all of

this period the great mass of these islands, including the Philippines, continued as the remains of the Cathaysian land, though this was beginning to suffer slow submergence around the margins. We are at present entirely in the dark regarding the Palæozoic formations of Formosa. Indeed it is not absolutely certain that marine Palæozoic formations occur at all upon this island, though the geological map of Japan indicates the presence of Palæozoic rocks. If such are present they probably belong to the Permian transgression, in which case the north-eastern margin of Cathaysia on our map should be modified accordingly. As there is a possibility that these beds are purely continental, or may even belong to the Mesozoic rather than to the Palæozoic, Formosa and the surrounding district have been included in the northern part of Cathaysia on our map.

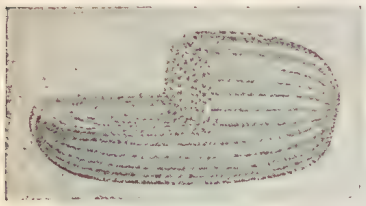

Fig. 244.

Doliolina lepida Schwager; entire individual, sectioned to show structure × 6. (After Schwager),

Japan, etc. In Japan we find the following two series of limestones:

Upper, with *Schwagerina verbecki*, Geinitz (Fig. 243), *Noeschwagerina globosa* Yabe, etc.

Lower with *Schwagerina verbecki*, *Doliolina lepida* (Fig. 244), *Neoschwagerina craticulifera* (Fig. 241), and *Fusulina japonica*,

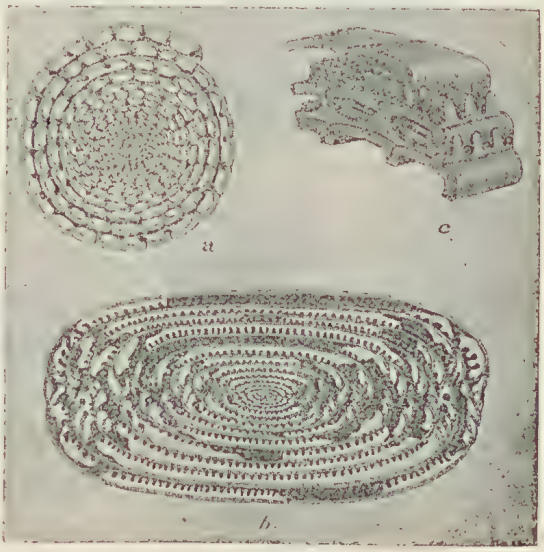

Fig. 245.

Diliolina lepida Schwager; *a*, transverse median section showing the low broad chambers × 8; *b*, median longitudinal section showing the regular strong septa (basal skeleton) × 8, *c*, diagrammatic section showing the disposition and strength of the transverse septa (basal skeleton); much enlarged. (After Schwager).

These apparently belong to the same late Uralian or early Permian transgression. Beds with *Fusulina* and brachiopods regarded as representing the Schwagerina zone of Russia, are found at Vladi-

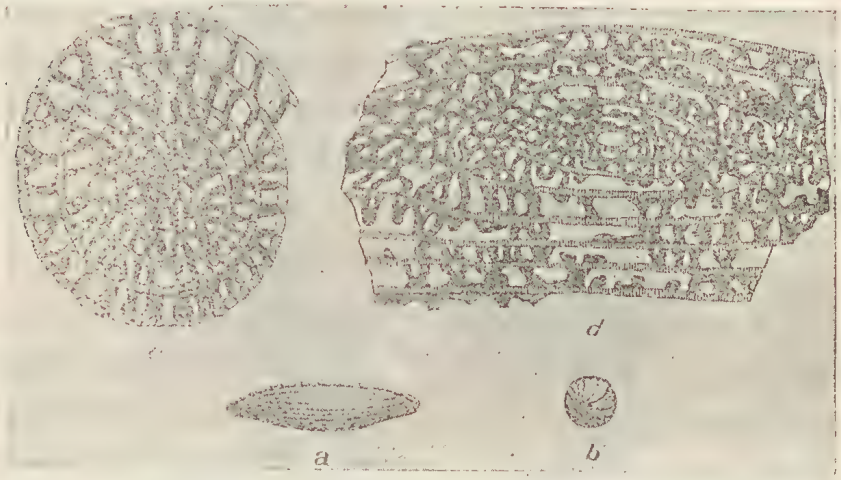

Fig. 246. *Fusulina richthofeni* Schwager, *a*, *b*, large individual side and end views × 1¾; *c*, cross-section, slightly excentric × 9; *d*, part of a longitudinal section × 9. (After Schwager).

vostok, and others with *Fusulina* related to *F. richthofeni* Schwager (Fig. 246), and with *Bigenerina bradyi* Müller are found in

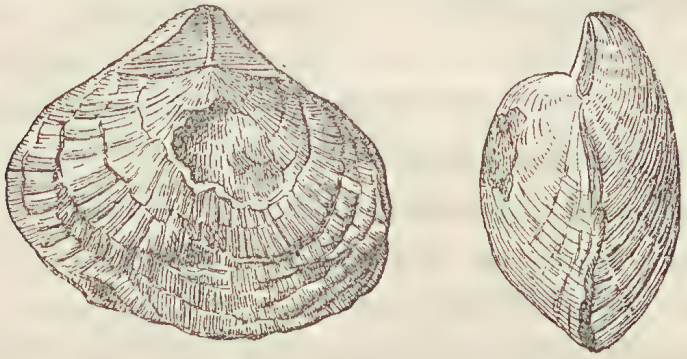

Fig. 247. *Orthotetes tingi* Grabau.

Korea. These two probably indicate the early Permian transgression from the Pacific border, which finally effected a junction with the transgressing waters in the Mongolian geosyncline. (See below).

From Yajagi-mura in the Kitakami Mountains (the northern half of the folded land occupying the Pacific side of northern Japan and north of Sandai Bay) a series of fossils has been obtained which have recently been described by Hayasaka (47) and which indicate the presence there of Permian strata. The following species comprise this fauna: *Productus flemingii* de Kon., *P. horridus* Sowerb, *P. vishnu* Waagen, *Spiriferina cristata* Schellw., *Dielasma* cf. *biplex*. *Camarophoria humbletonensis* Howse.

SOUTH-EASTERN AND CENTRAL CHINA.

Hunan. On the banks of the Lui-ho at Lei-pa-Kou and Huang-i-kang, in southern Hunan, extensive coal-bearing strata of Upper Permian age are exposed.* These beds carry the Gigantopteris flora (Schenk 83) and in some places contain a fauna of small pelecypods and gastropods in plastic blue clay associated with the coal. Of the 10 species definitely identified, 6 occur in the upper Productus limestone of India, while several of the others are related to late Carboniferous species in America.** This is regarded by some as the highest division of the Permian in China, bordering on the Triassic, while others consider it early Permian. (See further section on *Gigantopteris* flora).

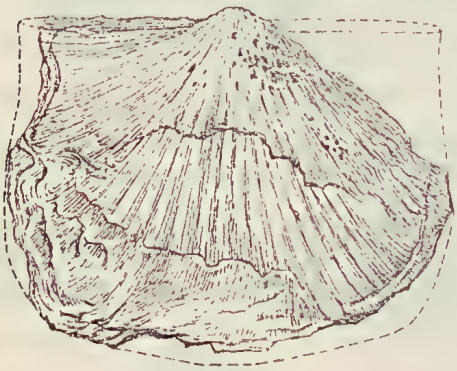

Fig. 218.

Orthotetes anderssoni Grabau, imperfect shell.

Kiangsi. East of the preceding locality in southwestern Kiangsi province, in the Chi-an-fu and Young-hsien districts, the following succession is shown according to T. C. Wang. (99).

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* Richthofen—III, pp. 455–457.

** For description of the fauna see Frech, in Richthofen China, vol. V, p. 185.

4. Super-formation Jurassic (*T'ienho series*).

Hiatus and disconformity.

3. Permian.

d. *Fêngt'ien series*.....200 meters
Shales, sandstones and five or more coal-seams with marine fossils in the upper part. These include the brachiopods *Reticularia*, *Enteletes* and *Productus*, and the goniatite *Glyphioceras anfuense* Gr. Plant fossils of the *Gigantopteris* flora occur.

c. *Hsiaochiang* (*Hsiaochiangpien*) *limestone*. 40 meters
Black impure limestones, sometimes white and cherty, in places very fossiliferous. The most characteristic species are: *Orthotetes tingi* Grabau (Fig. 247), *Orthotetes carinostriata* Grabau, *Orthotetes anderssoni* Grabau (Fig. 248), and *Spiriferina chuchuani* Grabau (See Appendix).

This Fauna may be called the *Orthotetes tingi* Fauna.

2. Permo-Carboniferous or Upper Carboniferous.

b. *Aochêng series* .....140 meters
Shales and sandstones with several coal-seams, and sometimes with iron ore in the upper sandstones. Only indeterminate plant-remains occur in this series.

Hiatus and disconformity

1. Pre-Carboniferous subformation: (a *Yunghsin series*)

In north-eastern Kiangsi, east of Poyang lake, lies the famous locality of Loping from which von Richthofen obtained an extensive fauna, which was described by Kayser (55) and Frech (31).

The relationships of the beds, as determinated by von Richthofen and more recently by W. H. Wong, are shown in the annexed section (Fig. 249). Kayser regarded this fauna as of Upper Carbon-

iferous age, but Frech referred it to the Permian. The fauna is characterized by brachiopods, pelecypods, and cephalopods, many of which are identical with, or related to, species found in the Salt Range. Of the twenty-nine brachiopods, fifteen occur in the Salt

Fig 249. Section of the coal-bearing beds of the Mong-shan or Loping Basin in Kiangsi (Modified after Richthofen).

1. Red and yellow sandstone, about..... 50 ft.
2. White marly limestone with nodules of very hard limestone containing marine fossils, about..... 10 ft.
3. Dark gray sandy coal shales. Finely bedded with indistinct plant remains including a thin coal bed of poor quality, about.....240 ft.
4. a Light gray dark marly limestone, rich in marine fossils
   b Black marly shales with marine fossils
   c Dark sandy coal shales.
   Total thickness, about.....100 ft.
5. Main coal bed, about..... 10 ft.
6. Shales and sands, thickness unknown
7. Ancient reddish shales and quartzites of Möng-shan.

Range, but only one is restricted to the upper Productus limestone, four to the middle, two range from the lower to the middle, six range from middle to upper, and two range throughout the three divisions. Of the ten pelecypods, one occurs in the lower, one in the middle, and two in the upper Productus limestone, one of the two gastropods ranges through the middle and upper Productus limestone, and of the six cephalopods one is restricted to the lower part of the upper Productus limestone. This clearly indicates that the Loping fauna corresponds to the middle Productus limestone.

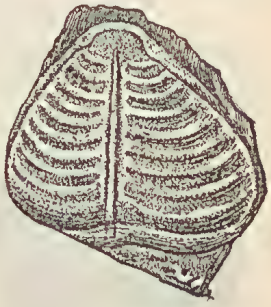


Fig. 250.
Lyttonia richthofeni(Kays.)

One of the most characteristic fossils of this horizon is the peculiar brachiopod *Lyttonia* (Fig. 250) which is widely distributed in China, and occurs also in outer Mongolia, in Japan, and near Vladivostok as well as in Indo-China (Cambodia, Annam, Laos),

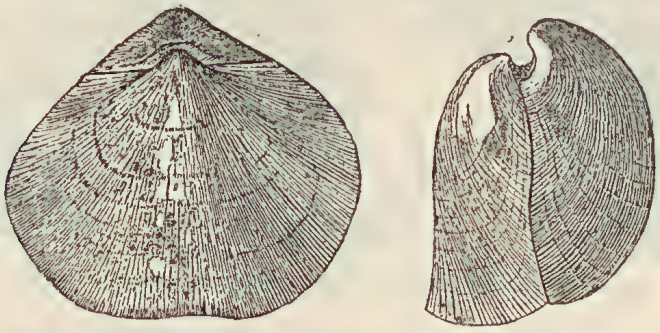


Fig. 251. *Martinia triquetra* Gemm. var. *lopingensis* Gr.

in Siam (Luang-Prabang) and on Timor. All of the species of this genus are restricted to the middle Productus limestone of India, and the genus is also known from the Permian of Palermo in the Mediterranean region, and from southern Texas, U. S. A.

The Loping fauna also occurs in the Wu-hsien district of southern Kiangsu, and in the Tao-Chun region of east Anhui. It is

again found near Ki-Kiang-hsien in Szechuan, and at Tung-tze-hsien in Kwei-chow. Some of the characteristic species of the fauna are shown in figures 250-255.

The exact age of the Loping fauna depends on that of the middle Productus limestone. By some it is considered Middle Permian, and by others Upper Permian.

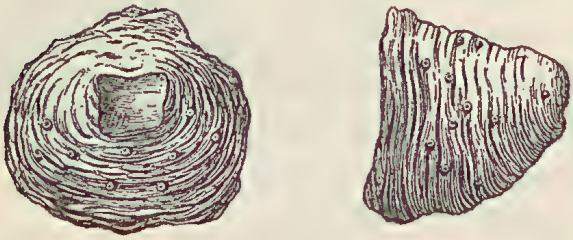


Fig. 252. *Richthofenia laurentiana* front and side views of attached valve.

The Loping fauna is probably older than the *Orthotetes tingi* fauna (Hsiao-chiang limestone p. 316) of Chian, Kiang-si. As shown above, that horizon is succeeded by beds with *Gigantopteris*. (See Appendix).

Southern Kiangsu and Northern Chekiang Provinces. In the Nanking Hills, south of the Yangtze, the late Dinantian beds are succeeded disconformably by beds of Permian age, though it is

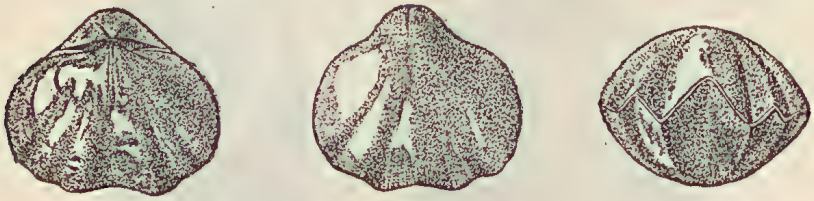


Fig. 253. *Enteletes kayseri* Waagen; three views. Loping.

possible that between the beds which have furnished the Permian fauna and those which carry Viséen corals, there is a horizon representing the Chinese Permo-Carboniferous, i. e., the Shansi series of north China. The succession, according to Messrs. Yih, Liu and Chao, is as follows (Fig. 256) in descending order.

Permian.

Chinglingshan or Chingling limestone.....300 meters

Light to dark gray limestone, thin-bedded.

Lungtan coal series..... ..... 82 meters.

Coal-bearing series with a bed of *Productus* limestone.

LOWER PERMIAN OR PERMO-CARBONIFEROUS (may possibly include some Uralian at the base.)

Ch'uanshan or Chuan limestone.....450 meters.

Dark gray limestone with cherty layers near the base; and in some cases sandy and shaly beds with fire-clay.

Hiatus and Disconformity.

UPPER DINANTIAN

Chihsiashan or Chihsia limestone..... 86 meters.

Gray fossiliferous cherty limestone, with typical Viséen

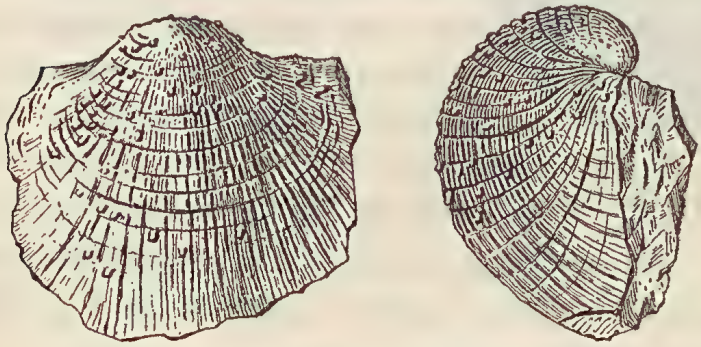


Fig. 254. *Productus sumatrensis* var. *palliata* Kays.

corals in the lower 30 meters. Possibly the upper part represents the Taiyuan series.

Hiatus and Disconformity.

LOWER SILURIAN (Niagaran).

Wutungshan or Wutung quartzite.....600 meters.

Reddish to white compact quartzite, no fossils: at base ferruginous shale and sandstone.

Kaochiapien shale.....200 meters.

Shale with trilobites and graptolites.

Hiatus and Disconformity

LOWER ORDOVICIAN

Lunshan limestone..... .....220 meters.

The majority of the species found in the limestones of the Lungtan coal series, range from the middle to the upper Productus limestone of India. One of the most characteristic brachiopods is *Orthotetes pectiniformis* var. *nankinensis* Grabau (Fig. 257), which is related, and perhaps ancestral to *O. tingi*. This and the general character of the fauna suggests that it precedes the horizon of *Orthotetes tingi* but succeeds the Loping horizon. The latter is found some distance to the south in the Wu-hsien district, while across the Chekiang border, in the Chang-hsing coal district, the limestone in the Lungtan coal series again carries large Producti, and the remarkable genus *Oldhamina*, which in the Salt Range occurs in the middle and upper Productus limestone. The species appears to be the same as the one found in India, i.e., *O. decipiens* (de Kon.) (Fig. 258).

Fig. 255.
Reticularia inæquilateralis.

Summary. From the facts now known, it would appear that the order of succession of these Permian faunas is as follows (in descending order):

3. Orthotetes tingi Fauna.
2. Oldhamina decipiens Fauna of Lungtan Coal Series.
1. Lyttonia richthofeni Fauna (Loping Fauna)

Below the Loping fauna apparently belongs the fauna of the Shansi Series of North China (see beyond) which is Lower Permian or Permo-Carboniferous.

Tsingling Geosyncline. In the Choutien district of northern Szechuan, near the south-western border of Shansi, and involved in the folds of the southern ranges of the Tsingling-shan, is the succession of strata shown in the following section (after Richthofen) (Fig.

259 p. 370). The beds are overturned to the south, so that the lowest member (a) appears on top. The succession is as follows, in descending order:*

f. Gray limestone with chert nodules. Corals and brachiopods are present in great number but difficult to extricate. *Reticularia waageni* (Fig. 260) is characteristic.

e. Alternations of nodular limestone layers 4-5 inches thick, with thin layers of dark brown bituminous shale, and pyroschist, carrying brown ironstone. The pyroschists are full of marine organic remains, especially *Productus intermedius* var. *subplicatilis* Frech, *Ambocœlia planoconvexa*, and pelecypods related to those found in the higher Coal Measures of America. *Gastrioceras* cf. *zitteli* Gemm. (Fig. 257a), and *Agathiceras* cf. *suessi* Gemm. were also found.

d. Yellow and gray fossiliferous shales including in their upper part a four foot seam of bituminous coal.....15 ft.

c. Alternations of gray limestone with *Reticularia waageni* and siliceous shales, 5 to 6 inches thick, with *Marginifera ovalis*..... .....12 ft.

b. Heavy-bedded limestones, with much chert, especially near the bottom, where it forms layers.

a. Unfossiliferous limestone in beds 4-6 inches thick, separated by marly shale layers 2 to 3 inches in thickness.

The series rests either disconformably or with a fault-contact against the overturned Silurian beds. The age of these beds is Permo-Carboniferous and Permian. The lower beds may correspond to the Loping horizon, though no diagnostic species have been obtained, or

* For description of fauna, see Frech in Richthofen, China, Vol. V, p. 139.

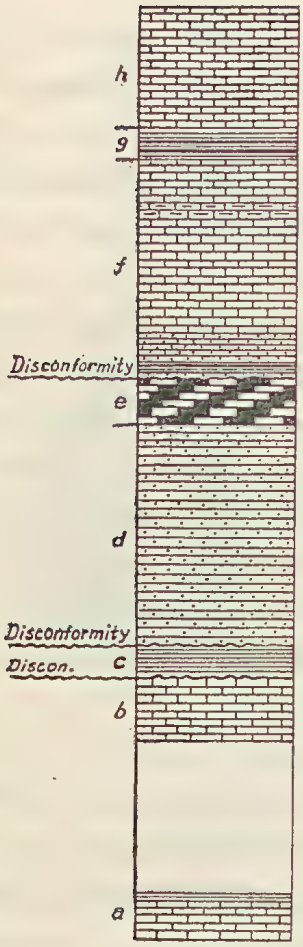


Fig. 256.

Columnar section of the Nanking Hills (After Yih, Liu & Chao).
a, Cambrian
b, Ordovician limestone (Lunshan limestone
c, Lower Silurian (Niagaran) graptolite shales
d, Wutungshan quartzite (Silurian)
e, Chihsiashan limestone (Dinantian)
f, Chuanshan limestone (Permo-Carboniferous or Permian)
g, Lungtan coal series (Permian)
h, Chinglingshan limestone (Permian).

they may belong to the horizon of the Shansi series the others are of Permian age.

So far as known from fossils, the Taiyuan fauna has not been found in this section, though the lower limestones which have yielded no fossils, may belong to that horizon. Bed *b* is said to show coralline structures. Elsewhere in this region these Carboniferous beds rest upon Devonian strata, which are evidently cut out in the section given.

In the mining district of Tao-Chung in Anhui, late Permian beds with the *Gigantopteris* flora have recently been discovered by Hayasaka (50). The plants, which are identified as *Gigantopteris dentata* Yabe, occur in the black shale exposed along the eastern side of the great incline near its middle. The beds dip about 70 degrees to the south and at an horizon about 140 meters below the plant beds in a sandy shale, several marine fossils were found, including *Gastrioceras zitteli* (Fig. 257*a*) and species of *Marginifera*. The goniatite was originally described by Gemmellaro from the younger Palæo-Dyas limestone of Sosio, Italy; the same species has also been described by Frech (31, (2)) from the higher beds of the Tapashan section in Szechuan (see Fig. 259, bed *e*), in limestone probably of the same horizon as that carrying the *Gastrio-*

ceras in Anhui. In Taochung, Hayasaka found a species of *Tetrapora*, probably identical with *T. elegantula*, which has been found in Fukien, where *Gigantopteris dentata* is also found, though the association of the two forms is not clear.

The *Gastrioceras zitteli* horizon is again found in southeastern Hupeh where it has recently been discovered by Mr. C. Y. Hsieh. It there consists of yellowish and reddish shales which form the lower part of the Tayeh formation, 500 meters or more in thickness, this consisting chiefly of thin-bedded limestones intercalated with shales. No fossils have been found in the limestone, but it is succeeded by the Jurassic coal series (Wuchang formation). *Gastrioceras zitteli* is very abundant, but is mostly flattened upon the shale. Associated with it is a new species

Fig. 257.

Streptorhynchus pectiniformis var. *nankinensis* Grabau. Nanking.

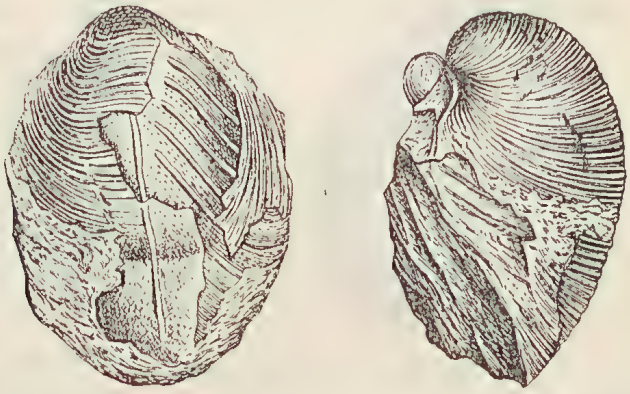


Fig. 258. *Oldhamina decipiens*. Side view, and valve with shell partly broken away.

G. liui Gr. These beds rest upon an earlier Permian formation, the Tangshanwan coal series, which includes some limestone beds

containing early Permian fossils. This series in turn, rests disconformably upon the Yang-sing limestone, 400 meters or more in thickness, a part of which is of Viséen age, containing characteristic brachiopods and corals. It in turn rests upon a thick formation of Silurian

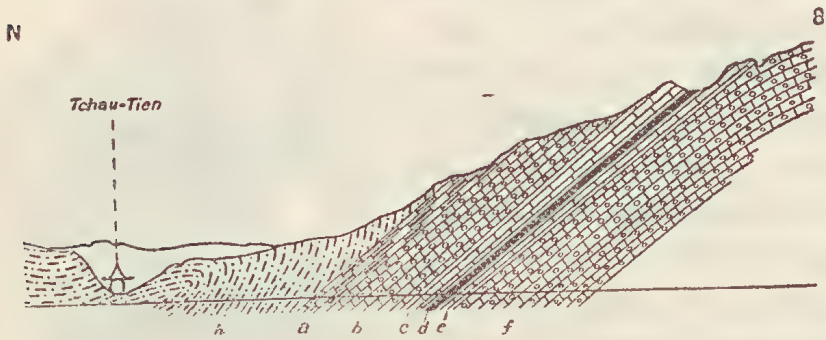


Fig. 259. Section of the Permo-Carboniferous rocks of Tapashan near Tshau-tien (Choutien), N. Szechuan. (After Richthofen). The lettering corresponds to the description in the text (p. 367).

age (Fuchihkou or Fuchih series). *Gigantopteris* has not yet been found in association with these Permian beds but probably occurs above the horizon of *Gastrioceras zitteli*. (See Appendix).

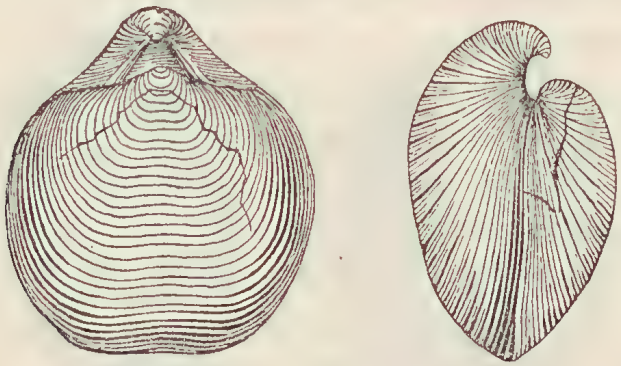


Fig. 260. *Reticularia waageni.*

North-West Chinese Basin. In northern Kukunor and in the Sominow mountains, Permian *Doliolina* limestones are found presenting the following sub-divisions in descending order:

3. Pale red and gray limestones, the latter with occasional *Doliolina*.
2. White oölitic limestone without fossils.
1. Massive gray limestone with *Neoschwagerina craticulifera* (Fig. 214), *Schwagerina verbeeki* (Fig. 243), *Fusulina* sp., *Fusulinella* sp., *Schwagerina princeps* (Fig. 215).

These Doliolina beds are concordantly succeeded by Lower Triassic strata, though it is probable that, as in all known cases, there is a disconformity and hiatus between these beds.* Nevertheless, these beds probably represent in part at least, late Permian. Elsewhere in this region, beds of similar age have been found. A gray limestone on the southern slope of the Seminow mountains, resembling the Doliolina limestone, contains a fauna indicating its age to be Lower Permian. The following fossils have been found: *Pinna* sp., *Camarophoria* sp., *Richthofenia* sp., *Spiriferina* cf. *subcristata*, *Enteles carnicus*. From Kansu, Dr. W. H. Wong has obtained limestones and shales of Permian age, the former with the goniatite *Gastrioceras*. (See Appendix).

Fig. 261.

Gastrioceras (*Girtyites*) *zitteli*. Gemm. (After Frech).

NORTH CHINA

Shansi. The best known succession of late Palæozoic and early Mesozoic beds in north China is that given by Mr. Norin (74) in the following section in central Shansi (Fig. 262) as modified in his article of 1924 (75).

Upper Permian.

Shichienfeng Series. .....700 meters.

This comprises the following subdivisions.

---

* See discussion of this question in Chapter X.

2. *Sandstone Zone.* Well stratified sandstones often cross-bedded, rarely with shales. Prevailing color red, brown and chocolate-brown, no plant remains or gypsum.....500 meters.

1. *Gypsiferous Marl Zone.* Chocolate-brown argillaceous shales and claystones, often marly and gypsiferous, and layers of sandstone. No plant remains .....150 meters.

LOWER PERMIAN.

SHIHHOTSE SERIES.....450 meters.

2. *Upper Shihhotse Series*.....280 meters.

b. *Ginkgo Zone.* Chocolate-colored, sandy argillaceous shales and claystones, interbedded with white or yellow sandstones and plant-bearing yellowish green and dark green shales... .....120 meters.

The flora of the highest bed of this zone is characterized by large-leaved *Ginkgophytes.*

a. *Gigantopteris Zone.* Alternating light colored shales and chocolate-colored sandstones with the *Gigantopteris* flora at bottom and top.

1. *Lower Shihhotse Series.* Mostly light-colored marls, shales, and thin sandstones and coal In the lower part of the series species of *Tæniopteris*, together with large-leaved *Pterophyllum*, *Sphenophyllum*, etc. This is a Lower Permian or Rothliegende flora .....160 meters.

SHANSI SERIES (restricted) (Permo Carboniferous)...65 meters.

Shales, sandstones and thin coal-seams; near the middle a plant-bearing bed with *Cordaites* and *Annularia*, and somewhat lower, a marine limestone (TUNGTAYAO LIME-

STONE) 3.2 meters thick. This contains *Enteletes* cf. *kayseri*, *Chonetes tungtayaoensis*, *Productus subcostatus* (Fig. 262), *P. pustulosus*, and *Spiriferina octoplicata*. Below it are 30 meters of shales, sandstones and some thin coal-seams.

Hiatus and disconformity.

DINANTIAN.

TAIYUAN SERIES, with many marine limestones (See p. 253)

About .....125 meters.

Hiatus and disconformity.

ORDOVICIAN.—Machiakou Limestone.

THE SHIHHOTSE series is of Permian age, both divisions, the lower and upper, falling approximately into the Lower Permian. The lower division consists chiefly of argillaceous deposits of fluviatile origin with grayish greenish and yellowish colors. The upper series is formed by a thick complex of sediments beginning with the lower *Gigantopteris* sandstone, and the red-brown clays subjacent to this. Its lower part comprises the GIGANTOPTERIS ZONE with ferns of this type predominating, and its upper the GINKGO ZONE with *Ginkgophytes* predominating.

The sediments of the upper Shihhotse series contain the products of a lateritic weathering process, and appear to have been formed during a period of very humid and hot climatic conditions, while the succeeding SHIHCHIENFENG series is marked by characteristics indicating an arid climate.

The flora of the upper Shihhotse series is distinctly Palæozoic such typical genera as *Annularia*, *Asterophyllites*, *Sphenophyllum*, *Sigillaria*, and *Cordaites* occurring. "A Permian age is indicated by such forerunners of the Mesozoic flora as *Tæniopteris*, *Plagiozamites* and *Baiera* which, in the Palæozoic of Europe, are almost exclusively confined to the Permian, and it is placed beyond doubt by the occur-

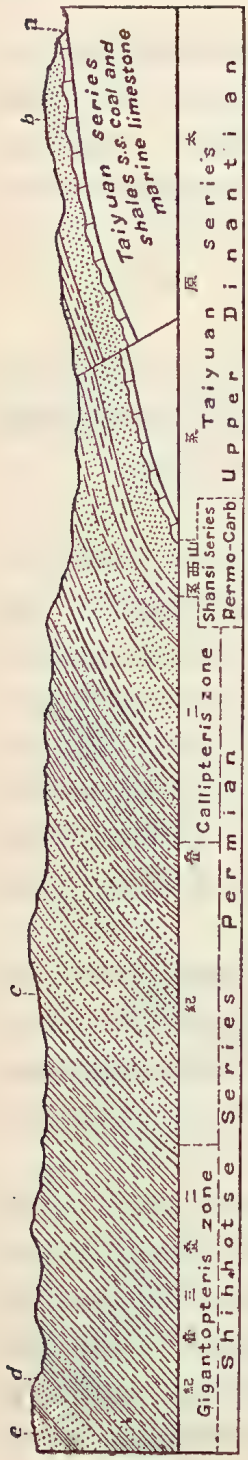


Fig. 262. Section in the Shih-ho-tse Valley, Shansi, showing the Carboniferous and Permian beds, (modified after Norin). *a*, Kuantikou limestone (Taiyuan Series); *b*, Peitsakou sandstone (Shansi series); *c*, lower *Gigantopteris* sandstone (Shihhotse Series); *d*, upper *Gigantopteris* sandstone (Shihhotse Series); *e*, base of *Ginkgo* zone (Shihhotse series).

rence at a somewhat lower level of *Sphenophyllum thonii*, one of the most distinctive species of the Permian". (Halle in Norin 74 p. 23). Halle considers that the upper Shihhotse series falls within the limits of the Lower Permian, the Rothliegendes of central Europe. "This is confirmed by the almost total absence of conifers, notably of Zechstein forms". The so-called Ginkgo sandstone is however, of more doubtful age, "being characterized by numerous *Psygmophyllum*-like leavelets of unknown affinity and containing for the rest only little significant species of *Tæniopteris* and *Baiera*." Halle summarizes the character of the flora in the following words:

"The flora differs from the European Permian in several important respects. The genus *Callipteris*, which is the most distinctive type of the Permian of Europe, is entirely absent not only in the Upper Shihhotse series but in all collections from supposedly Permian deposits of Shansi" examined by Professor Halle. "Of conifers, too, not only Zechstein forms are wanting, but hardly any undoubted trace of *Walchia* has been found, though that genus would be expected to occur in any large material of Lower Permian plants.

"The peculiar character of the flora as compared with that of the European Lower

Permian, however, is due especially to the occurrence of a number of forms which seem to be characteristic of the Permian of the Far East. The most important of these types is the genus *Gigantopteris* to which belongs the most distinctive species of the Upper Shihhotse series.

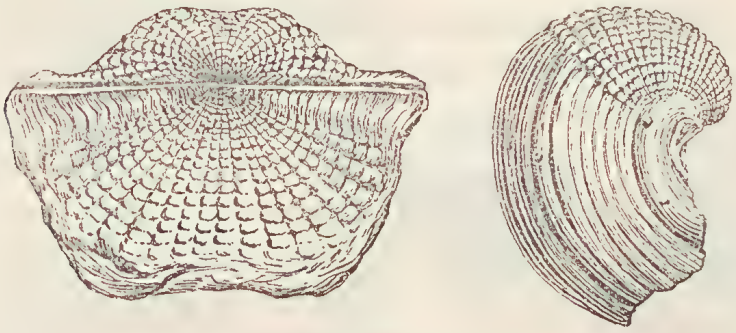


Fig. 263. *Productus subcostatus* Waagen.

Another type peculiar to the Permian of eastern Asia is represented by a set of forms of *Annularia* closely related to *A. maxima* Schenk, but probably better separated as a distinct species. *Gigantopteris* and *Annularia maxima* were first described by Schenk from von Richthofen's material collected at Luipakou (Leipakou), and Luiho (Leiho) in Hunan. (See below). The flora of the Upper Shihhotse series is evidently closely related to this much discussed Luipakou flora which in Hunan, however, is characteristic of the beds immediately connected with the main coal seams." Halle concludes that it is "impossible to decide to what extent the difference between the Upper Shihhotse flora and the contemporaneous flora of Europe may be due to edaphic factors or regional contrasts." The difference is probably "largely due to isolation in different phytogeographical districts." Several of the forms of these beds indicate a near relation to the Permian of North America.

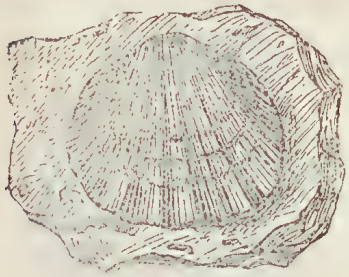


Fig. 264.
Meekella kayseri Jaek.

The detailed petrographic studies of Norin have brought out the interesting fact that the characteristics of the Shihhotse sediments agree closely with those of modern laterites. This is seen among other characters in the presence of considerable quantities of free hydrate of alumina, which in certain levels equal or exceed 10% by weight. In this respect these sediments agree remarkably well with the primary laterites of Madagascar, which are of Quaternary age.

Fig. 265.

Remeleoceras subquadrangulare Grabau; *a*, side and *b*, dorsal view of a fragment; Shansi.

Another characteristic of these sediments is the formation during the weathering processes, of much free silica, which occurs as concretions of chalcedony and silicified wood. The silica is not uniformly distributed, but occurs in certain horizons, as in modern elluvial and alluvial laterites.

The upper boundary of the Shihhotse series is formed by red-brown argillaceous sand and clay, impregnated with iron hydrate, which also occurs in concretions of various shape and size, not infrequently forming continuous beds one half to one inch in thickness. With these iron concretions occurs an abundance of amorphous silica, in the form of carneol and chalcedony concretions, or as silicification of the sediments.

Fig. 266.

Temnocheilus asiaticus Grabau. Shansi.

These characteristics are wide-spread and constant at this stratigraphic horizon in the Permian of Shansi, and are due to those chemical rearrangements which are everywhere produced in lateritic alluvial deposits when these become exposed to arid climatic conditions for a considerable period of time. This then, marks a period of changing climatic conditions in this region during later Permian time, the warm humid climate giving way to an arid or desert climate while at the same time the well-drained lands were converted into extensive undrained continental areas. This is probably to be correlated with the period of complete withdrawal of the marine waters from the Asiatic continent at the close of Permian time as will be more fully discussed in the next chapter.

Fig. 267.
Euphemus wongi Grabau. Shansi.

In western Shansi, the lower Taiyuan beds (Paloukou limestone, etc.) are succeeded, according to T. C. Wang (99), by plant-bearing shales of black and bluish color, 1.4 meters in thickness, and these are followed by the main bituminous coal beds of the region 15.7 meters thick. Immediately overlying the coal is the PAOTECHOU LIMESTONE, 10 meters thick, which abounds in fossils. Besides the species found in the Tungtayao limestone, there are many others, including several species of *Enteletes* and *Orthotetes*, also species of *Productus*, *Meekella kayseri* (Fig. 264), *Spiriferina chuchuani* Gr., *S. octoplicata*, *Aulacorhynchus paotechouensis* Gr.; several very characteristic new pelecypods; a large *Bellerophon* (*B. anderssoni* Gr.) and a number of cephalopods (*Huanghoceras simpli-*

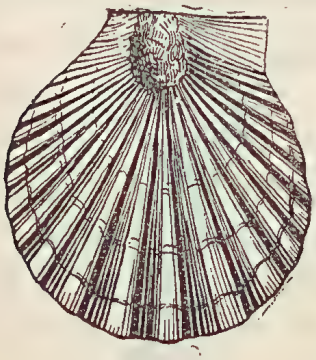


Fig. 268.
Pseudomonotis mathieui Grabau; left valve × 3. Kaiping Basin.

costatum Gr., *Remeleoceras subquadrangularis* Gr. (Fig. 265), *Temnocheilus asiaticus* Gr. (Fig. 266), *Metacoceras* sp., etc.).

Above the Paotechou limestone follows a coal bed and shale 0.4 meters thick, and this is followed by the T'UMEN FORMATION,

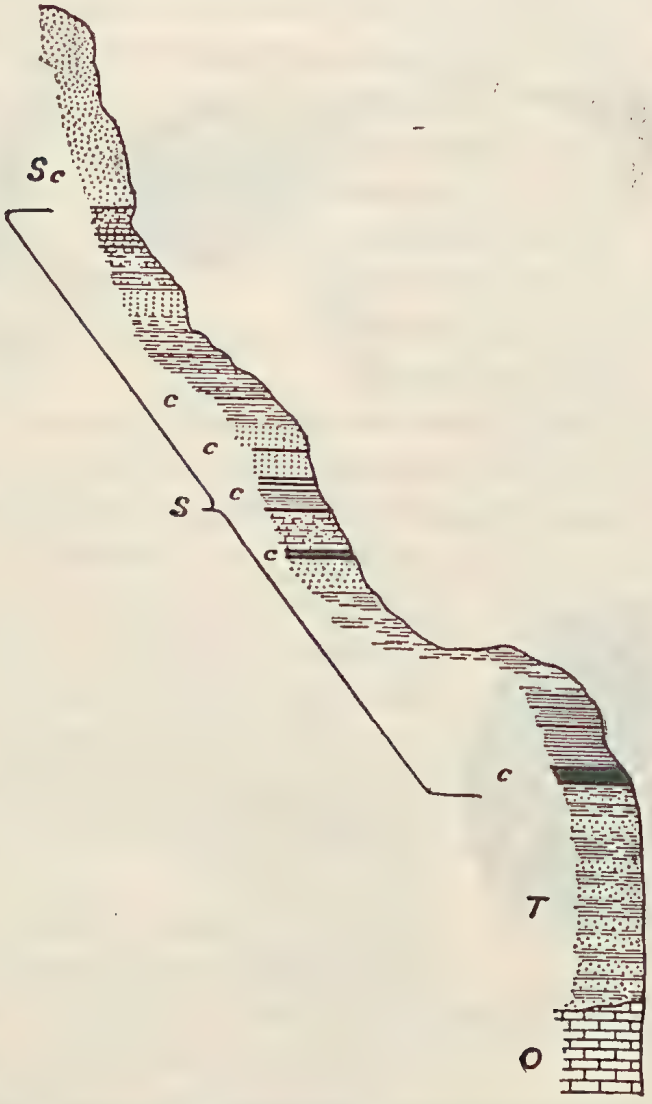


Fig. 269. Section of the coal-measures, Tien-Hua district, north Shansi (after Willis); O, Ordovician limestone; T, Taiyuan shales and sandstones (non-calcareous); S, Shansi series; Sc, Supra Carboniferous red sandstone and conglomerate (cross-bedded) cc, coal.

fourteen meters thick, and consisting of shales at the bottom, capped by a massive limestone and a shale with limestone nodules. The fauna of the T'umen formation is especially rich in gastropods, twelve species having been identified so far. The most characteristic of them are *Euphemus wongi* Grabau (Fig. 267), and species of *Soleniscus* and *Naticopsis*. Among the pelecypods occurs *Pseudomonotis mathieui* Gr. (Fig. 268) and other species. Several brachiopods of the

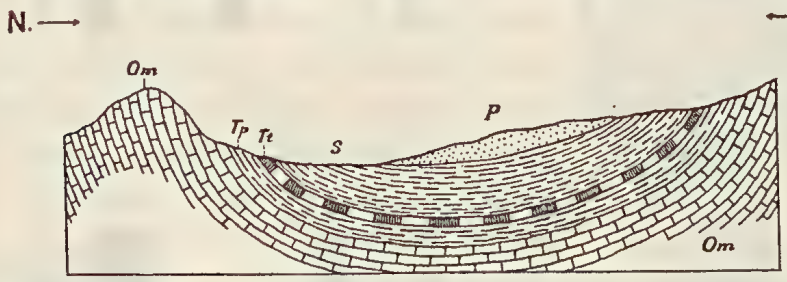


Fig. 270. Section of the Kaiping Coal Basin. *Om.* Machïakou limestone (Ordovician); *Tp,* Peioutze shales and sandstones (Taiyuan Series); *Tt,* Tangshan limestone (Taiyuan series); *S,* Shansi coal-measures(Permo-Carboniferous); *P,* Supra Carboniferous red beds(Permian?).

Paotechou horizon also occur. The general succession of the Shansi and Taiyuan Series in the Tien Hua district, Shansi is shown in Fig. 269.

CHIHLI. In eastern Chihli the Shansi series begins with shales and sands which rest disconformably upon the Taiyuan beds. There are several thin marine intercalations, but only one of these, the CHAOKOUCHUANG ARGILLUTYTE, about 35 meters above the Tangshan limestone, has yielded determinable fossils. They include a number of species of *Productus*, and *Spiriferina chuchuani* Gr., and other brachiopods; also *Pseudomonotis mathieui* Gr. (Fig. 268) (Grabau 38).

The fauna is Lower Permian or Permo-Carboniferous, and the bed containing it succeeds coal seam No. 13. Above this are twelve other coal seams, as shown in the several sections in the

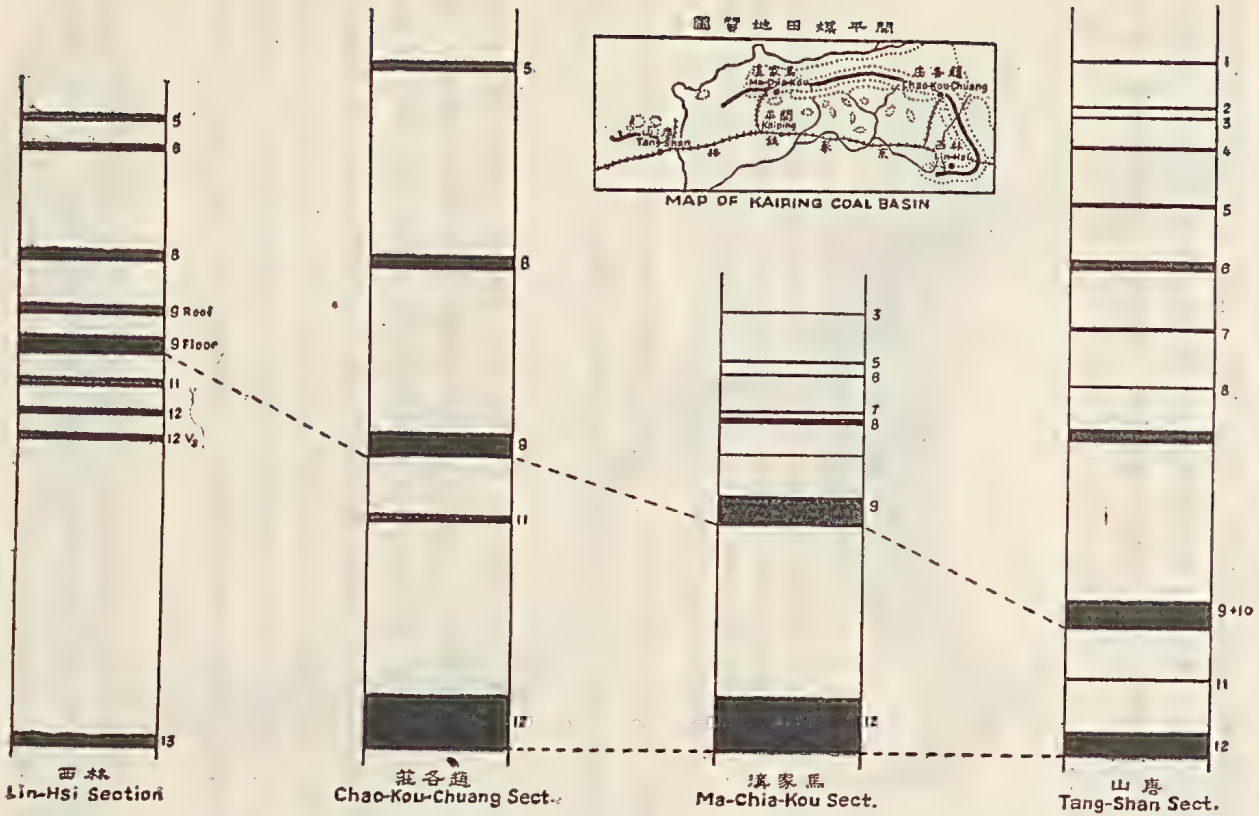


Fig. 271. Columnar sections of the coal-bearing strata of the Kaiping Basin. The formations are all within the Shansi series. The numbers 1 13 indicate the successive coal beds. The locations of the sections are shown on the small map.

Kaiping basin (Figs. 270-271). The coal seams carry a rich flora but animal remains are scarce. Those found include a small *Spirorbis?* and an *Eurypterus*, the first one found in China (Grabau 37). This has been named *Eurypterus chinensis* Grabau (Fig. 272) and it is a characteristic representative of the life of the rivers and ponds of the region in Permo-Carboniferous time.

Fig. 272.

Eurypterus chinensis Grabau × 2.

Flora of the Kaiping Basin. There are two distinct floras in the Kaiping basin, one belonging to the Taiyuan series, the other to the Shansi series which alone carries workable coal seams. The flora of the Shansi series combines elements of the Stephanian and younger horizons with some holdover types of Westphalian age.*

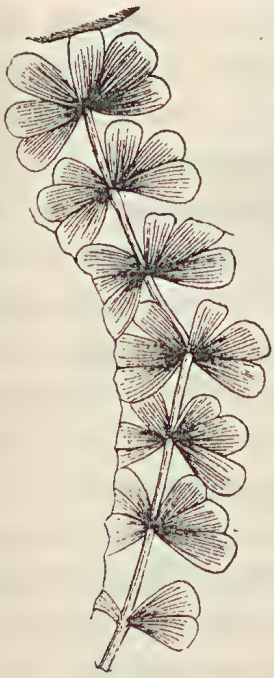


Fig. 273.

Sphenophyllum verticillatum × ½.

The flora of the Kaiping Basin is at present only partly known but the following species have been obtained, according to Schenk, Kersten, Mathieu (65) and T. H. Chao: *Eremopteris* cf. *courtini*, *Pecopteris cyathea* (Fig. 275 a, b), *P. arborescens* (Fig. 185, p. 269), *P. lepidorrhachis*, *P. platoni*, *P. sterzeli*, *P.* cf. *unita*, *P.* cf. *hemitelioides*, *Alethopteris* sp., *Callipteridium* cf. *pteridium* (Fig. 186, p. 270), *Odondopteris genuina*, *Desmopteris elongata*, *Tæniopteris multinervis*, *T. jejunata*

* The flora will be described and illustrated in the *Palæontologia Sinica*, Series A.

(Fig. 276), *Neuropteris scheuchzeri*, *N. flexuosa*, *N. gigantea* (Fig. 274), *Aphlebia* cf. *germari*, *Calamites cisti*, *Annularia stellata* (Fig. 187, p. 270), and var. *mucronata*, *Sphenophyllum emarginatum*, and var. *truncatum*, *S. verticillatum* (Fig. 273), *S. oblongifolium*, *Lepidodendron oculus-felis*, *L. gaudryi*, *Lepidophyllum hastatum*, *Stigmaria ficoides*, *Cordaites principalis*, *Artisia approximata*, *Zamites* cf. *regularis*.

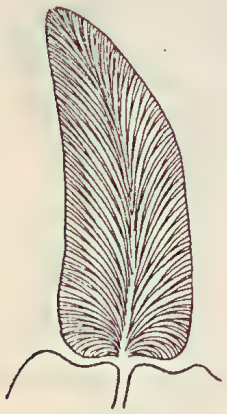


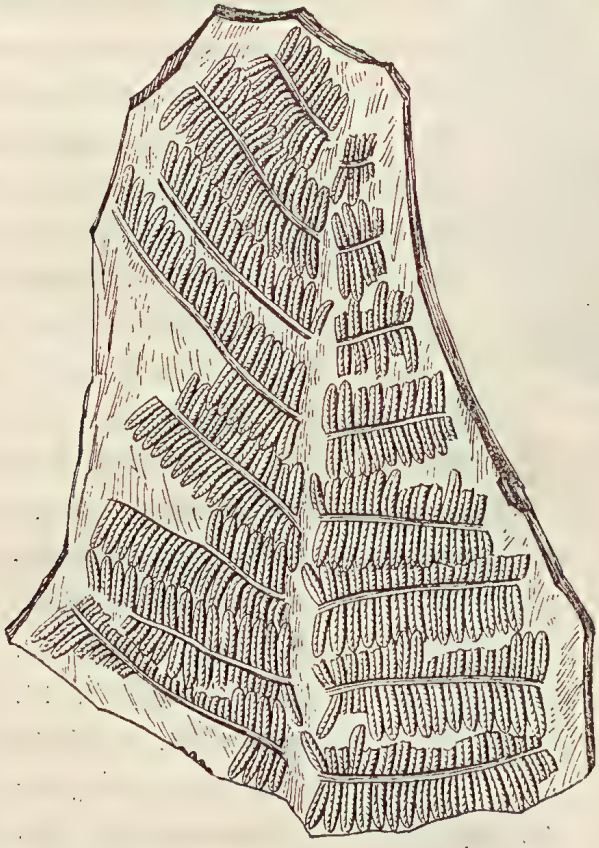
Fig. 274.
Neuropteris gigantea.

Mathieu calls attention to the strong affinities of this flora with that of the Commentry basin in France, which is Permo-Carboniferous or early Permian in age.

Recently Mathieu has reported some plant remains from the roof-shale of an upper coal bed at Tang-Chia-Chwang, in the Kaiping basin. These include *Neuropteris* cf. *flexuosa*, *Sphenophyllum emarginatum*, *Lepidodendron oculus-felis*, etc., which indicate Permian age. In the upward succession of floras, the common species become more and more rare most of them disappearing completely, only *Cordaites* and *Annularia stellata* persisting. At the same time two other species: *Tæniopteris multinervis* and *Sphenophyllum thonii*, which are relatively rare in the lower beds, become more and more abundant, finally giving the entire flora its characteristic aspect.

Shantung. In Shantung the coal-bearing beds were classed by Willis and Blackwelder as the Poshan Series (318 meters thick) and the succeeding Permo-Mesozoic red beds as the Sint'ai Series (275 meters in thickness). The recent studies of Mr. H. C. Tan (91) have shown that the coal series is divisible into two groups as in Shansi. The lower division is about 100 meters thick and rests disconformably upon the Ordovician (Machiakou) limestone. It carries some coal and two limestone beds with the fauna of the

Taiyuan series of Shansi. To this division Mr. T'an has restricted the name POSHAN SERIES. The higher division carries many coal beds and is apparently of Permo-Carboniferous age, resting disconformably upon the lower division. This is called by Mr. T'an the



Ffg. 275a. *Pecopteris cyathea* Brongt. ⅔

HUNGSHAN SERIES. It contains no marine fossils. The adjoining section (Fig. 277 p. 385) from Willis and Blackwelder's volume, shows the general succession of the strata.

MANCHURIA. Permo-Carboniferous coal-bearing deposits are known from the Pen-Hsi-Hu coal basin in southern Manchuria, some 40 miles south of Mukden on the Mukden-Antung Railway line. These were originally described by von Richthofen, and the flora from

these beds by Schenk and subsequently by Zeiller, the latter of whom, refers the deposits to the Permo-Carboniferous. Other species from this region were described by Yokoyama and more recently the basin was investigated by Mathieu (69). According to him there are eight workable coal beds, furnishing an excellent coal, especially serviceable for the manufacture of coke. The beds rest on a thick series of Ordovician limestones and are covered by unfossiliferous quartzite. At the eastern extremity of the basin there is an important eruptive mass of porphyry similar to that found in the Shi-Men Chai coal basin of northern Chihli. The flora of the coal beds includes the following species: 1. *Neuropteris flexuosa* (?), 2. *Pecopteris arborescens*, 3. *P.* cf. *densifolia*, 4. *Odontopteris* sp., 5. *Callipteridium orientale*, 6. *Alethopteris* (?), 7. *Tæniopteris multinervis*, 8. *Calamites* sp., 9. *C. cisti*, 10. *Annularia stellata* (*mucronata*), 11. *Sphenophyllum oblongifolium*, 12. *Lepidodendron oculus-felis*, 13. *L.* aff. *gaudryi*, 14. *Lepidophyllum* sp., 15. *L. hastatum*, 16. *Cordaites principalis*, 17. *Samaropsis affinis*, 18. *Pachytesta gigantea*, 19. *Pterophyllum* (?) *carbonicum*, 20. *Stigmaria ficoides*.

Fig. 275b.
Pecopteris cyathea Brngt. two pinnules enlarged.

In commenting upon this list, Mathieu observes, that certain of these species (Nos. 1, 9, 10, 16) are of little stratigraphic volue, having a great vertical range. They are all met with in the Westphalian and continue to the summit of the Stephanian and even into the Permian. *Lepidodendron oculus-felis*, as it occurs in China, is near certain Westphalian and Stephanian

Fig. 276.
Tæniopteris jejunata.

species of Europe. It is very abundant in the Kaiping basin where it has a great vertical extension. It even occurs beneath the Tangshan limestone (Taiyuan Series). Certain other species, such as Nos. 2 and 3 have a strong Stephanian affinity, while continuing into the Permian. *Taeniopteris multinervis* is a guide fossil characterizing the Lower Permian, especially in the basins of Antung and Epinac. Most of the species found in the Pen-Hsi-Hu basin also occur in the Kaiping basin in similar stratigraphic relation. As in the Kaiping basin, the coal beds of Pen-Hsi-Hu are preceded by a limestone which appears to be the equivalent of the Tangshan, having furnished crinoid stems and *Spirifer* cf. *bisulcatus*. In both these basins it is of interest to note the persistence of older types of plants, *i.e.*, those of Westphalian and Stephanian age, though these are mostly species of little stratigraphic value.

In the Hon-Kei-Ko, Yentai, and other coal fields of southern Manchuria, the Cambrian limestone (in the Hon-Kei-Ko field it is

Fig. 277. Partial section of the Carboniferous and Sin t'ai (Upper-Permian.) strata at Yen-chuang, Shantung showing intrusive volcanic rocks. (After Blackwelder). *a*, purple and yellow shales; *b*, gray sandy shale and sandstone; *c*, variegated shales; *d*, maroon shales and yellow sandstones; *e*, black shale; *f*, greenish sandstone and shale; *g*, basalt dikes and sills; *h*, yellow shale; *i*, variegated shales and gray sandstone; *j*, gray sandstone; *k*, red sandy shale; *l*, buff syenite-porphyry; *m*, gray and pink sandstone with local seams of conglomerate; *n*, red sandy shale: *o*, syenite porphyry dike; *p*, green stratified tuffs; *q*, basalt dike; *r*, dark gray sandstone.

Ordovician (?) limestone) is disconformably succeeded by a thin complex of shales and sandstones, with small lenticular masses of limestone. These contain marine fossils of late Carboniferous or early Permian age, and mark a marine invasion from the Pacific on the

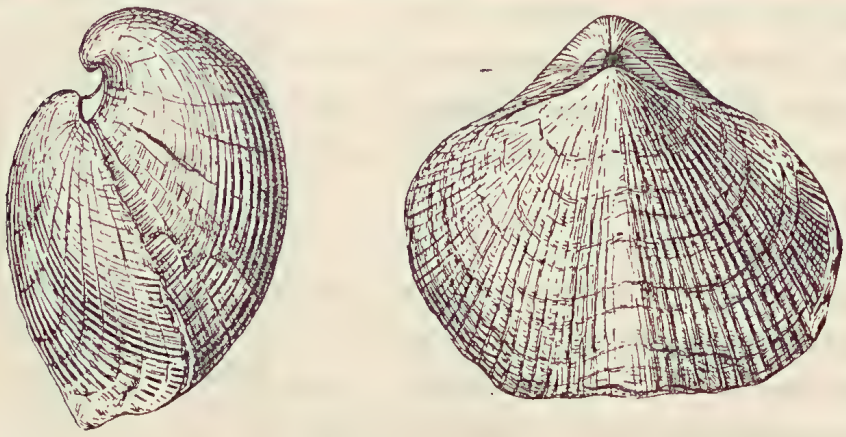


Fig. 278. *Spirifer nikitini* Tschern.

east, where the same fauna is found in the vicinity of Vladivostok, and in Korea. The fauna is essentially the same in all the sections, but the best material so far known has been described from the Hon-Kei-Ko Coal field (Hayasaka 49b).

Fig. 279. *Spirifer winnii* Waagen.

The species definitely identified are the brachiopods *Marginifera timanica* Tschernyschew, *Spirifer jigulensis* Stuckenberg, *Sp. nikitini* Tschernyschew (Fig. 278), *Sp. tschernyschewi* Stuckenberg, *Sp. supramosquensis* Nikitin (Fig. 183, p. 268), *Sp. winnii* Waagen

(Fig. 279), *Martinia semiplana* Waagen *Martiniopsis baschkirica* Tschernyschew, and the corals: *Arachnastræa manchurica* Yabe and Hayasaka, *Cystophora manchurica* Y. and H., *Chætetes asiaticus* Y. and H., and *Syringopora reticulata* Goldfuss.

The fauna is of the horizon of *Schwagerina princeps* Ehrenb., that species being found in the Hei-jo coal fields in Korea, associated with related forms, i.e. *Chætetes asiaticus* Y. and H., *Caninia muratai*

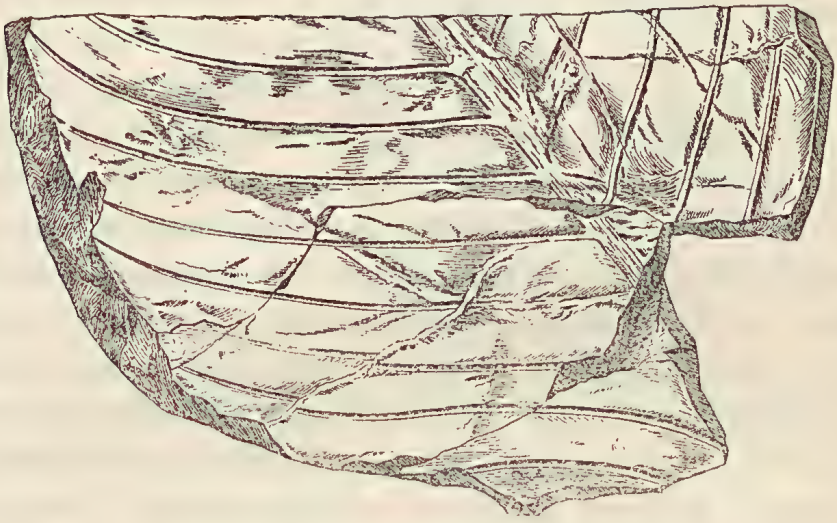


Fig. 280. *Gigantopteris nicotinæfolia* Schenk.

Y. and H., *Cystophora dubia* Y. and H., *C. kikkanai* Y. and H., *Arachnastræa coreanica* Y. and H., etc. This HEIJO fauna is at present unknown from China, and represents a distinct invasion along a northern passage-way (Fig. 229 p. 325).

In the Yen-tai coal fields, the HONKEIKO beds with *Sp. nikitini* etc. are conformably succeeded by the continental Yen-tai or Lower Coal series. This is 1017.6 feet thick, and consists of shales and sandstones in alternation with 11 coal seams, each varying in thickness from 1 to 5 feet. Three of these, each five feet thick, are important producers. There are two plant horizons, one 150 to 180 feet above the Honkeiko marine beds, and the other 420 feet above these beds. The

latter with an upper Stephanian flora contains *Gigantopteris nicotinæfolia* (Fig. 280). This will be more fully noted below. The upper coal series in the Yen-tai field is 267.7 feet thick, and consists of shales and sandstones in alternation with 4 coal seams, each varying in thickness from 2 to 7 feet.* No floras have been discovered in this series.

The upper coal series is succeeded by a thick sandstone formation with some intercalation of shale.

The Gigantopteris Flora

The *Gigantopteris* flora was first discovered by von Richthofen at Lui-pa-Kou, in the coal field on the Lui-ho in Hunan. (See above). The fauna was described by Schenk (83), who in 1883 named the new large form found in these beds *Megalopteris nicotinæfolia*. The species was subsequently referred to the genus *Gigantopteris*. Among the species of plants associated at Lui-pa-Kou with *Gigantopteris nicotinæfolia* (Schenk) (Fig. 280), are the following: *Annularia maxima* Schenk, *Cyclopteris trichomanoides* Brongn. *Neuropteris* cf. *flexuosa* Sternb. *N. angustifolia* Brongn.,** *Pecopteris* cf. *unitus* Brongn., *P.* cf. *miltoni* Goeppert,*** and *Cordaites principalis* Germar.

The age of these beds was believed by Schenk to be Carboniferous, but later Zeiller referred them to Lower Triassic, while David White regards them as of Lower Permian age. Yabe agrees with White.

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* I follow Yabe Science Rep. Tohoku Imp. Univ. 2nd Ser. Vol. IV. No. 2 p. 64. In Vol. I. Coal Resources of the World, p. 247 the lower coal series is said to contain 13 seams and the upper only three, only one of which, 2 to 5 feet thick, is being worked.

** Regarded by David White as a new species, also known from Lower Permian of Texas.

*** Specific reference questioned by D. White.

Gigantopteris nicotinæfolia Schenk (Fig. 280), is again found in the coal-bearing series of Yentai in southern Manchuria, where it occurs in association with the *Taiso coal*, about 420 feet above the base of the series. Associated with it are: *Odontopteris reicheana* Gutbier, *Neuropteris scheuchzeri* Hoffman, *Callipteridium* cf. *pteridium* Schlotheim, *Calamites* cf. *suckowi* Brgt., *Annularia inæquifolia* Tokunaga, *Sphenophyllum oblongifolium* Germar and Kaulfuss, *Lepidodendron oculis-felis* Abrado, *Stigmaria ficoides* Sternberg, etc. Zalessky, Yokoyama and Yabe refer this flora to the uppermost Stephanian. At the base of the series are beds with marine fossils representing the *Schwagerina princeps* zone of the late Uralian (see *ante*), and Yabe holds that the Yentai flora is to be referred to the Lower Permian. As the species of *Gigantopteris* is the same as that of Lui-pa-Kou, Hunan, that horizon is also regarded as Lower Permian. It is, however, more probably Middle or early Upper Permian.

a

Fig. 281a. *Gigantopteris dentata* Yabe (Korea).

In the Province of Yunnan, the *Gigantopteris* flora seems to be wide-spread. It was first described from Mi-leu and Tou-tsa by Zeiller, who identified the leading species as *G. nicotinæfolia*. Yabe however refers this to a new species, under the name of *G. dentata*

(Fig. 281a,b.) differing from the first species in the denticulate margin, and the character of the veination. Zeiller referred the horizon of these plants to the Lower Triassic, but David White points out, that in comparison with the Texan occurrence, the horizon should be regarded as Permian. A collection made by Dr. V. K. Ting, from the districts of Hüan-Wei and Tung-chuan in Yunnan, is now exhibited in the Museum of the Survey. The following account of this flora and its occurrence is contributed by Dr. Ting.

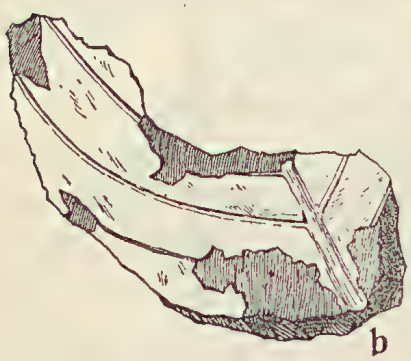

Fig. 281b. *Gigantopteris dentata* Yabe.

The formation from which the specimens come undoubtedly corresponds to that of Mi-leu and Tou-tsa as they occur in exactly the same stratigraphical position. The fossils found are as follows:

1. From Erh-tao-ch'ing 二道溝 Tung-chuan 東川 Yunnan, Lower plant bed *Tæniopteris abnormis* Gutbier, *Tæniopteris* sp., *Pecopteris* cf. *polymorpha* Brgn., *Gigantopteris nicotianæfolia* Schenk (*G. dentata* Yabe); and, from a slightly higher horizon: (upper plant bed) *Ptychocarpus tingii* Halle* *Dictyophyllum* sp.,

2. From Lu-tzai-p'ing 綠菜坪 Hüan-wei: *Annularia maxima* Schenk, *Pecopteris* cf. *cyathea* (Schloth.) Brgn., *Gigantopteris nicotinæfolia* Schenk (*G. dentata* Yabe).

3. From Chien-chia-kou, 錢家溝 near T'ang-t'ang 倘塘 Hüan-wei, 宣威: *Tæniopteris* sp., *Pecopteris* sp., *Annularia* sp.

4. From Nien-fei, 念非 Hüan-wei: *Sigillaria* cf. *oculifera* Weiss.

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* T. G. Halle, Fossil Plants from southeastern China. Palæontologia Sinica Ser. A. Vol. I. (in press) 4 plates, 59 pages.

"Prof. Halle who had made these determinations points out the intermingling of Palæozoic and Mesozoic forms especially in the collection from Erh-tao-ch'ing where the occurrence of *Dictyophyllum* gives the flora a distinct Mesozoic aspect. In spite of this, however, it is probably late Permian or at least Permo-Triassic, as the presence of *Annularia* and *Sigillaria* clearly indicates.

"This coal series occupies everywhere in Yunnan the same stratigraphical position, namely, always between the Permian basaltic lava and the Triassic sandstone and which consists of yellowish and brownish fine-grained sandstone of no very great thickness. As all the overlying series are certainly marine in origin, it seems more logical to group this terrestrial formation with the underlying lavas, hence the argument in favor of regarding it as Permian is still more strengthened.

"The formation contains three seams of coal each of about one meter in thickness, and not far from one another. All the seams are of excellent quality and are worked by natives. In Tung-chuan the coal is made into coke for the purpose of smelting lead and copper."

The horizon with *G. dentata* Yabe has been found in a number of other localities in Yunnan.

The flora with *Gigantopteris dentata* has again been found in Fukien, in the coal-bearing series which overlies limestone with *Fusulina* and underlies the red beds of that province. At the Liu-Shan-tou coal mine this species was found associated with another new species of *Gigantopteris* and with *Sphenophyllum* aff. *speciosum* Royt., *Equisetum serrani* Zeiller, *Pecopteris* sp. etc. *G. dentata* has also been obtained from Anhui (See *ante* p. 368).

In Shansi, the *Gigantopteris* flora has been found by Norin at a horizon 230 to 290 meters above the highest marine horizon, the

Tungtayao limestone of Lower Permian age. Its position is thus between 190-250 meters above the top of the Shansi series. Norin refers it to the Lower (more probably Middle or early Upper) Permian.

The same horizon is again found in Chi Rando, in the Heijo coal field, Korea, where it overlies the *Jido series*. The coal-bearing formation of the Jido series is contemporaneous with that of Yentai, Manchuria, the age of which, as noted above, is Lower? Permian. Hence the Chikando horizon is a higher one. It contains (1) *Gigantopteris dentata* Yabe, (2) *Merianopteris? heijoensis* Tok., (3) *Nœggerathia? kikkawai* Tok., (4) *Tæniopteris* cf. *multinervis* Weiss, (5) *Annularia inequifolia* Tok., (6) *Nœggerathiopsis hislopi* Bunbury (*N. æqualis* Gœpp. see beyond), (7) *Zamites truncatus* Zeiller, (8) *Phyllotheca* cf. *indica* Bunbury, and (9) *Neuropteridium* sp. nov. In neighbouring localities occur, (10) *Tæniopteris lancefolia* Koiwei, (11) *Cheiropteris* sp. nov., and (12) *Sphenophyllum* sp. nov. Numbers 4 and 5 of this list give to the flora a Palæozoic aspect, while numbers 6 and 8 are forms which characterize the Gondwana flora (called Permo-Carboniferous by some and Permo-Triassic by others). Numbers 2,7,10 and 11 are forms with a decidedly Mesozoic aspect; and number 9, which is of the type of *Neuropteridium voltzi*, is a typical Triassic plant. From this, the conclusion is drawn that this flora is not older than Upper Permian and not younger than Lower Triassic.

Fig. 282.

Glossopteris browniana. Newcastle beds New South Wales. × ½.

There are thus two *Gigantopteris* horizons, one in the Lower? Permian the other at the top of the Permian, where the forerunners of the Mesozoic types of flora had already made their appearance.

It is of interest to note the presence in this flora of the widespread *N. hislopi* (*N. æqualis*) characteristic of the southern or Gondwana Flora with *Glossopteris* (Fig. 282).

Supra-Carboniferous Continental Formations.

(See Fig. 262 p. 374 and Fig. 283).

China. The rocks of this series represent the continental sediments which were deposited over the coal formations in north China. They are of fluviatile and in part of eolian origin, and include conglomerates, sometimes with pebbles several inches in diameter, arkoses, red sandstones, and sandy shales, and white sandstones with eolian cross-bedding. Banded sandstones, gray quartzites, and grits also occur. The red-beds and the arkoses indicate, that the period during which they were deposited was one of semi-arid, and in part perhaps of desert climate. This is also shown in the western part of China, where these Supra-Carboniferous red-beds include gypsum and rock-salt. Beds of this type constitute the surface rock of large parts of the Red Basin of Szechuan, and probably many of the saline waters of China receive their salt content from the solution of salt beds or scattered salt crystals in these Red Beds. The characteristics of some of these beds in Shansi have already been referred to (p. 376).

The age of these beds is probably in part late Permian, though some portions may represent the deposits during the Permo-Triassic interval, and may be of Mesozoic age. They indicate that towards the close of the Palæozoic, the relatively moist climate of China, under which the coal swamps existed, and the lateritic deposits were formed, was replaced by a dry climate, while large areas probably became deserts. From this time onwards the sea no longer covered north China, though for a short period in Triassic time, marine conditions were temporarily reestablished, especially in south China.

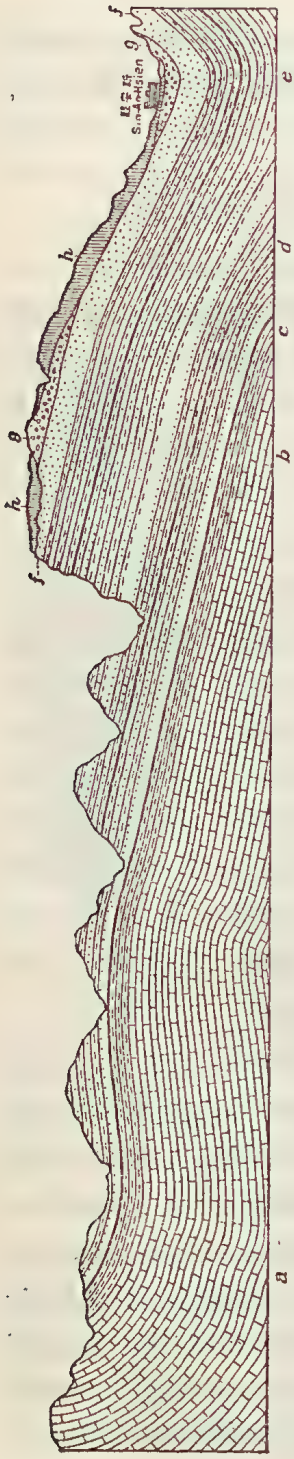

Fig. 283. Section of the Permo-Carboniferous beds of Honan, resting upon Ordovician limestones and followed by Supra-Carboniferous red beds and loess. Sin-An District, Honan (After Nyström). *a-b*, Ordovician limestone; *c-d*, Taiyuan; *e*, Shansi beds;—coal bearing; *f*, Supra-Carboniferous millstone grit (Permian); *g*, red sandstone (Permian or Triassic?); *h*, loess.

Lower Angara Beds of Siberia and Mongolia. From the lower part of the so-called Angara series, which is the name applied by Suess to the continental formation of the Siberian region (essentially Angara land), a number of Palæozoic species of plants have been described. It is probable that this Palæozoic continental series will eventually be definitely separated from the Angara formation, the age of which is primarily Mesozoic. It will here be referred to under the name of Kusnezk Series from the well known locality of that name. The following are the species which have been recorded by Zalessky (71): From Tarbagataï, Russia: *Psygmophyllum potanini* (Schmalhausen) (Fig. 284a), *Neurogangamopteris cardiopteroides* (Schmalh.) (Fig. 285), *Nœggerathiopsis æqualis* (Goeppert) (Fig. 286a), *Dicranophyllum lusitanicum* (Heer), *Volzia heterophylla* Brongniart (Fig. 284c). From Tangnouola Mountain, north-west Mongolia: *Neurogangamopteris cardiopteroides* (Schmalh.), *Nœggerathiopsis æqualis* (Goeppert), *Psygmophyllum potanini* (Schmalh.),

Lepidodendron schmalhauseni Zalessky. From Boukou-Mouren Steppe, Mongolia: *Psygmophyllum mongolicum* Zalessky (Fig. 287a), *P. potanini* (Schmalh.) (Fig. 284b), *Neurogangamopteris cardiopteroides* (Schmalh.), *Phyllotheca* sp, *Callipteris murenensis* Zalessky, *Samariosus* sp., *Dicranophyllum lusitanicum* (Heer). From the Upper Tunguska or Angara river, Siberia: *Glossopteropsis angarica* Zalessky (Fig.

Fig. 284. Plants of the Kusnezk Series. a, *Psygmophyllum potanini* Schmalh. Tarbagataï (Russia) × ½; b, *P. potanini* Schmalh. Bouken Mouren steppes Mongolia, nat size; c, *Volzia heterophylla* Brongn. Tarbagataï × ¾; d, *Phyllotheca deliquescens* (Goepp.). Lower Tunguska, Siberia ×½.

288a), *Psygmophyllum potanini* (Schmalh.), *Neurogangamopteris cardiopteroides* (Schmalh.), *Pecopteris anthriscifolia* (Goeppert). From the coal-bearing deposits of Minuzinsk, Abakan basin: *Cardiocarpus* sp., *Nœggerathiopsis æqualis* (Goeppert), *Neurogangamopteris cardiopteroides* (Schmalh.), *Neuropteridium sibiricum* Petunnikow, *Aneimites lopatini* (Schmalh.), *Phyllotheca deliquescens* (Goepp.), *Pecopteris anthriscifolia* (Goepp.). From the coal-bearing deposits of Minuzinsk and the Kirghiz Steppes: *Ancimites lopatini* (Schmalh.) (Fig. 288b), *Nœggerathiopsis æqualis* (Goepp.), *Lepidodendron kirghisicum*

Zalessky, *Caenodendron primaevum* Zalessky, *Angarodendron obrutchevi* Zalessky. From the Lower Tunguska: *Phyllotheca deliquescens* (Goepp.) (Fig. 284d), *P. equisetitoides* Schmalhausen (Fig. 289a), *P. schtschurowskii* Schmalhausen, *P. paucifolia* Schmalhausen, *P. stellifer* Schmalhausen (Fig. 289b), *Phyllopitys heeri* (Schmalh.) (Fig. 289c), *Equisetites* (*Equisetum*) *czekanowskii* (Schmalh.), *Gangamopteris glossopteroides* (Schmalh.) (Fig. 288c), *Czekanowskia rigida* Heer, *Pecopteris anthriscifolia* (Goepp.) (Figs. 290a, 291a), *Sphenopteris tunguscana* (Schmalh.) (Fig. 292a), *Cardiocarpus depressus* Schmalhausen, *Nœggerathiopsis æqualis* (Goepp.) (Fig. 286b), *Nephropsis integerrima* (Schmalh.), *Ginkgopsis czekanowskii* (Schmalh.). From the coal-bearing deposits of the Kusnezk basin: *Nœggerathiopsis æqualis* (Goepp.) (Fig. 286c), *N. cardiopteroides* (Schmalh.), *Phyllotheca schtschurowskii* Schmalhausen (Fig. 286d),

Fig. 285.

Neurogangamopteris cardiopteroides (Schmalh.) Kusnezk Series, Tarbagataï. × ⅞.

Fig. 286. Plants of the Kusnezk Series. a, *Nœggerathiopsis æqualis* (Goepp.) Tarbagataï; b, *N. æqualis* (Goepp.), Lower Tunguska; c, *N. æqualis* (Goepp.), Kusnezk basin; d, *Phyllotheca schtschurowskii* (Schmalh.) Kusnezk basin. All one half nat. size.

P. deliquescens (Goepp.) *P. socolowskii* (Eichwald), *Pityophyllum longifolium* Nathorst, *Glottophyllum cuneatum* (Schmalh.) Zalessky, *Callipteris altaica* Zalessky, *C. zeilleri* Zalessky (Figs. 290b, 291b), *Podozamites lanceolatus* var. *eichwaldi* Heer, *P. lanceolatus* Lindley, *Baiera parvifolia* Zalessky (cf. *Baiera pulchella* Heer), *Baiera zeilleri* Zalessky, *Cladophlebis adnata* (Goepp.) (Figs 287b, 290c), *Otopteris*

Fig. 287. Plants of the Kusnezk Series. a, *Psygmophyllum mongolicum* Zal. Boukou-Mouren Steppes Mongolia; b, *Cladophlebis adnata* (Goepp.) Kusnezk basin. × ⅔.

ovata McCoy (Fig. 293), *Neuropteris* sp., *Schizoneura gondwanensis* Feistmantel, *Czekanowskia rigida* Heer, *Alethopteris* (*Asplenium*) *whitbiense* Goeppert, *A. lindleyana* Royle, *Sphenopteris batchatensis* Zalessky, *S. muricea* Zalessky, *S. erosioides* Zalessky, *S.* aff. *matheti* Zeiller, *S. odontopteroides* Zalessky (Fig. 290d), *S. batchatensis* Zalessky, *S. polymorpha* Feistmantel, *Gangamopteris* cf. *buriadica* Feistmantel, *Neurogangamopteris cardiopteroides* (Schmalhausen), *Pecopteris anthriscifolia* Goeppert (Fig. 292b), *Dioonites inflexus* Eichwald "Salairsk", *Phoenicopsis angustifolia* Heer, *Odontopteris sibirica* Zalessky (Fig. 291c), *Neuropteridium validum* Feistmantel, *N. sibiricum* Petunnikow, *Cyathea tchichatchoeffi* Schmal-

hausen, *Samaropsis* sp., *Psygmophyllum cuneifolium* (Kutorga), *Cladostrobus lutugini* Zalessky, *Ginkgo* sp., *G. digitata* (Brongniart) (Fig. 290e).

Among these fossil plants *Nœggerathiopsis æqualis* (Goeppert Fig. 286a-c) appears to be one of the most characteristic. This was originally described by Goeppert as *Cordaites æqualis* and it has been

Fig. 288. Plants of the Kusnezk Series. a, *Glossopteropsis angarica* Zal. Upper Tunguska or Angara, Siberia; b, *Aneimites lopatini* (Schmalh.) Minuzinsk, Siberia; c, *Gangamopteris glossopteroides* (Schmalh.) Lower Tunguska. All one half nat. size.

shown by Zalessky that this is identical with *Nœggerathiopsis hislopi* (Bunbury) of the Gondwana flora (Talchir, Damuda and more doubtfully the Triassic beds).

In Western Siberia this flora has been traced over an area of many thousands of square miles, extending in a straight line over 2000 miles (Stoyanow 81). From the Tarbagataï mountains on the Russo-Mongolian frontier (between latidutes 47° and 48°, longitude

82° to 86°) these plant-bearing beds have been traced as far north as the Khatanga river, near the Arctic coast (long 105°). Eastward they have been traced to the vicinity of Lake Achit in the Valley of Lakes, and in the Taunu Ola mountains, about 1500 miles from the Ekibastus mines, in the Kirghiz Steppes, which is the westernmost point where the Palæozoic portion of the Angara series has been observed. In the region of Saisau lake, the Lower Carboniferous, which here rests on the marine Devonian, begins with conglomerates,

Fig. 289. Plants of the Kusnezk Series. a, *Phyllotheca equisetitoides* Schmalh.; b, *P. stellifera* Schmalh.; c, *Phyllopitys heeri* (Schmalh.). Lower Tunguska, Siberia. All one half nat. size.

clays, sandstones and interstratified volcanic breccias together with heavy flows of porphyrites and their tuffaceous varieties. In the western portion of the Tarbagatai mountains, the Lower Carboniferous is of marine character but further north continental and semi-continental conditions prevailed, the beds everywhere containing the Culm flora. The succeeding beds are sandy and shaly and include the coal measures. They are also interbedded with volcanic ash and flows, and contain the earliest representatives of the Angara flora. It has generally been held that these must have been of necessity true Carboniferous, since they succeed beds with the Culm flora and rest with apparent conformity upon these lower horizons. Since we know,

however, that elsewhere in eastern Asia, beds of very late Carboniferous or Permo-Carboniferous rest directly upon late Lower Carboniferous, as for example in the Chinese basin, where Lower Permian succeeds the Taiyuan series with apparent conformity, though in reality with a disconformity, the argument for the Carboniferous age of the lower Angara series loses much of its weight.

Fig. 290. Plants of the Kusnezk Series. a, *Pecopteris anthriscifolia* (Goepp.); b, *Callipteris zeilleri* Zal., Kusnezk Basin; c. *Cladophlebis adnata* (Goepp.) Kusnezk Basin; d, *Sphenopteris odontopteroides* Zal., Kusnezk Basin; e, *Ginkgo digitata* (Brongn.) *b-e* one half nat. size.

In the section northward from the Chinese border to lake Saisau, Stoyanow (81) finds the succession in general as follows: On the northern slopes of the Tarbagataï Mts. only Devonian and Culm beds occur "The lowest horizon of the Middle Devonian is of a striking appearance and seems to mark a transgression of the sea over an ancient land of unknown age and nature. It consists of very

ferruginous boulders up to one foot in diameter or even larger, cemented by white limestone filled with, or made up wholly of corals and Stromatopora." These bouldery limestones with corals represent the Kwenlun transgression in this region, and are succeeded by white limestones from which an American Hamilton fauna has been reported

Fig. 291. Plants of the Kusnezk Series. *a*, *Pecopteris anthriciifolia* (Goepp.) Lower Tunguska; *b*, *Callipteris zeilleri* Zal. Kusnezk basin; *c*, *Odontopteris siberica* Zal. Kusnezk basin. All one half nat. size.

(*Spirifer mucronatus* Conrad, *S. audaculus* Conrad, *Leptostrophia perplana* Hall and *Douvillina inæquistriata* Conrad). If these identifications are correct, this fauna would appear to represent the invasion of the Hamilton element across the Boreal region, probably at the close of Eifelian time, before the Hamilton sea was entirely cut off from these northern regions (compare Figs. 98, 101 and 102, pp.

153-158). These beds are in turn succeeded by Upper Devonian sandstones, from which American forms have likewise been reported, though the identification of these may perhaps be questioned (*Spirifer mesicostalis* Hall, *S. mesistrialis*, *S. disjunctus* (*S. verneuili* Murch.), *Hypothyridina cuboides* Sow. and in the highest beds *Dalmanella tioga*, *D. carinata*, etc.). The succeeding Lower Carboniferous (Dinantian) beds consist of clays, sandstones and conglomerates with interbedded

Fig. 292. Plants of the Kusnezk Series. *a*, *Sphenopteris tunguscana* (Schmalh.) Lower Tunguska; *b*, *Pecopteris anthriscifolia* (Goepp.) Kusnezk basin. One half nat. size.

tuffs carrying the Culm flora including *Asterocalamites scrobiculatus* (Fig.145.p.216) and *Lepidodendron volkmannianum* (Fig.195,p.275).

The succeeding supra-Carboniferous beds are found in the sunken plain of Chiylikty, which separates the Tarbagataï from the Monrak range next north. Here the coal beds of the series are capped by sandstones and compact shales with *Neurogangamopteris cardiopteroides* and *Nœggerathiopsis æqualis*. These supra-Carboniferous beds play a considerable part in the composition of the Monrak range, on the south slope of which they consist of almost vertical conglomerates, coarse sandstones, quartzite, thick tuffaceous sandstones and sandy shales. These again contain *Neurogangamopteris*

cardiopteroides (Fig. 285), *Rhacopteris potanini* Schmalh., *Dicranophyllum lusitanicum* (Heer), etc. Near the northwestern termination of the range, a thick series of hard white, reddish and yellow calcareous sandstones, contain fish remains in the lower portion, while the middle part is filled with shells of *Posidoniella lævis* Bronn. and *P. elongata* Phil. The upper beds contain beautifully preserved specimens of *Nœggerathiopsis æqualis* Goepp. Here, for the first time, these plant beds have been found associated with those carrying marine or brackish faunas. On the northern side of the Monrak range, bright-colored oölites also contain, near the top, shell-bearing sandstones with *Posidoniella elongata* Phil. and *P. variabilis;* these likewise are capped by conglomerates and sandstones with *Neurogangamopteris cardiopteroides* and *Dicranophyllum lusitanicum*. These *Posidoniella* beds apparently mark the last of the marine Lower Carboniferous beds, or they may be early Permian as in Kansu (See Appendix). They are followed by the coal series probably with a disconformity. In the south-eastern part of the Monrak range the supra-Carboniferous series overlies the Culm beds with *Asterocalamites scrobiculatus* from which it is separated by sheets of porphyry, etc. The succession of the beds here is as follows in descending order:

g. Thick series of shales interstratified with calcareous sandstones and carrying fish-remains in the upper, and *Modiola transversa* Hind and *M. megaloba* McCoy in the lower part.

f. Gray calcareous sandstones with the same *Modiolas*.

e. Black calcareous shales filled with *Modiola lata* Port., *M. megaloba* McCoy, *M. fabalis* de Ryckold.

d. Thin carbonaceous shales.

c. Thick calcareous sandstones with poorly preserved pelecypods.

b. Shaley slates.

a. Tuffaceous sandstones resting on the porphyry which overlies the Culm.

These *Modiola* beds belong to the Lower Carboniferous, and are succeeded by the *Posidoniella* beds previously referred to, which are in turn succeeded by the beds with the Kusnezk plants. There is here no indication whatever that the sequence is continuous, and it is quite probable that there is a pronounced hiatus and disconformity below the *Posidoniella* beds, and another between them and the beds with the Kusnezk plants. A discovery of considerable interest is the finding in the Kusnezk basin, and elsewhere, of freshwater pelecypods *Anthracomya phillipsii* Will., *A. lævis* Dawson and *A. minima* Ludwig. At Erunakovo these are found on the same slabs with well preserved specimens of *Nœggerathiopsis æqualis*. In the mines of Kolchugino, *Nœggerathiopsis æqualis* has been found together with *Parallelodon angustus* Hind. From this occurrence it would appear that *Nœggerathiopsis æqualis* had already appeared in this region at the time that these pelecypods existed. In Europe they are Upper Carboniferous types but that does not preclude the possibility that in Asia these may have continued into the Permian. To refer the Kusnezk flora to the Carboniferous merely on the strength of these pelecypods seems rather venturesome, especially when we consider the conditions which must have been instrumental in permitting migration of these species.

Fig. 293. *Otopteris ovata* McCoy. New South Wales and Kusnezk basin. × $\frac{2}{3}$. (Kusnezk Series.)

The flora of the Kusnezk Series is a remarkable combination of Palæozoic and Mesozoic types, as has frequently been remarked, but the Palæozoic forms predominate. In spite of the association of Carboniferous pelecypods it is probably to be classed as Permian. Another remarkable feature of the flora is an admixture of the southern or Gondwana types. We shall again refer to the Gondwana floras in connection with the discussion of the Jurassic floras (Chapter XIII) and it will then be shown that certain periods of extensive land connection existed when this flora could be distributed. So far as actual identity with forms occurring in the Lower Gondwana series, *i.e.* the *Glossopteris* flora, is concerned, this is very slight, the only forms being *Schizoneura gondwanensis*, a form occuring in the Talchir, Damuda and Panchet series of India and in New South Wales; *Phyllotheca deliquescens* found in the Newcastle sandstone of N. S. Wales; *Gangamopteris* cf. *buriadica*, a form characteristic of the Talchir division of India; *Sphenopteris polymorpha*, occurring in the Damuda beds of India and the Newcastle sandstones of New South Wales; *Nœggerathiopsis æqualis* (Goepp.), (*N. hislopi* (Bunb.)), of the Talchir and Damuda beds, and *Voltzia heterophylla* of the Talchir and Damuda divisions of India, and widely distributed in Europe as well. The occurrence of both *Glossopteris* and *Gangamopteris* in this Siberian flora indicates that there was a possibility of inter-migration between the northern and southern regions, as does also the occurrence of *Voltzia heterophylla* in the southern region, this being a typical northern form. From Soukhona and Petite Duina Russia, have been recorded three additional species of *Glossopteris* (*G. indica*, *G. angustifolia* and *G. stricta*), and two of *Gangamopteris*, *G. cyclopteroides* and var. *major* (Amalitzky 2, 3.). These beds occur intermediate between a Lower Permian horizon with *Lepidodendron* and *Calypteris conferta*, and sediments containing upper Zechstein Mollusca.

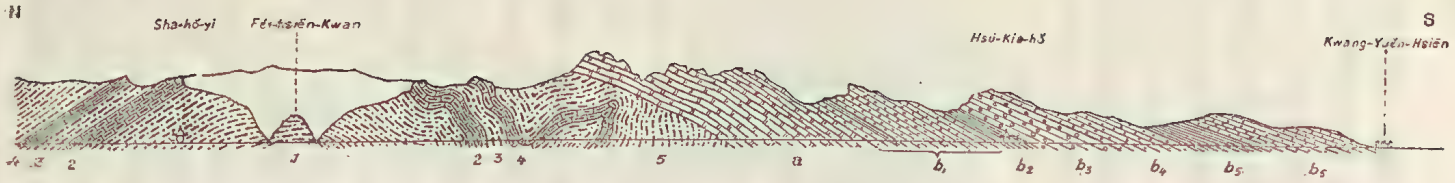

Fig. 294. Section in the valley of the Kia-ling-kiang, across the foot-hills of the Tsinglingshan, north Szechuan, showing the unconformable superposition of the Mesozoic on the Palæozoic strata. (After von Richthofen).

1. Great mass of red-brown and gray clay shales with irregular surfaces and many lamellæ of limestone. Thickness unknown.
2. Limestone, mainly of red-green color, ... 160 ft.
3. Greenish red and yellow clay shales, ... 200 ft.
4. Limestone well bedded, ... 90 ft.
5. Red and green clay shales with thin limestone layers, ...1000 ft.

1-5 regarded by Richthofen as Silurian.

a. Limestone series, red, yellow, green and white at the base, thin-bedded, followed by heavy-bedded limestone green and red, and becoming yellow upwards. Higher still yellow dolomites followed by grayish white limestone. Permian or Triassic according to Richthofen, possibly Rhætic. Dip 30° South. .....1200 ft.

b_1-b_2 Kwang-Yuan coal series. Jurassic.

b_1 Sandy and clayey beds of yellow and green color, thin-bedded coaly seams in the lower part, ...1000 ft.

b_2 Alternations of gray plant-bearing shales and soft sandstones filled with plant stems, includes two coal beds, each 3 to 4 ft. in thickness. Bituminous. Contains Lower Jurassic plants, ... 200 ft.

b_3 Thick beds of coarse conglomerates with pebbles of limestone and compact sandstone, coarsest near the base, ... 300 ft.

b_4 Yellow sandstone alternating with shales, ... 100 ft.

b_5 Coal, partly red-colored sandstones, ... 600 ft.

b_6 Thick-bedded green sandstones soft and friable, ... 500 ft.

Aside from these, however, the Kusnezk and Gondwana floras are quite distinct, showing that during the main period of development the regions were separated. It is possible that this northward migration of the Gondwana flora occurred during Carboniferous (pre-Permian) time, though so far as we know there were no direct land connections, and migration by way of Cathaysia can hardly be considered, since the Chinese Permian flora is entirely distinct, being characterized by *Gigantopteris*, except in Tonking where a remnant of the *Glossopteris* flora occurs. It is however, possible that this migration took place at the end of Permian time, when, as will be shown in the next chapter, there was a withdrawal of the sea and widespread land connections. In that case, however, this northern flora can not be considered as strictly of Permian age but rather as early Mesozoic, perhaps early Triassic, with a persistent Permian element. The Tonking flora, described by Zeiller (110-113) includes the following species of the *Glossopteris* flora, though the beds in which they occur are regarded as Rhætic in age: *Glossopteris indica* Schimper, *G. angustifolia* Brong., *Nœggerathiopsis hislopi* (Bunb.) (*N. æqualis* (Goepp.) Zalessky), *Palæovittaria kurzi* Feist., *Tæniopteris spatulata* M'Clelland, *T.* cf. *macclellandi* (Old. and Mor.) *Danæopsis* cf. *hughesi* Feist. (*Sphenopteris* cf. *hughesi* Feist.). It is however, of interest that from San-schi-li-pu, in the province of Shensi, China, two typical members of the *Glossopteris* flora have been obtained, namely *Danæopsis hughesi* Feist. and leaves resembling *Nœggerathiopsis æqualis* (Goepp.) (*N. hislopi* (Bunb.)). A *Schizoneura*, (*S. krasseri* Seward), was also found in Szechuan in beds regarded as of Rhætic age. The Rhætic flora of Taï-Pin-Tchang in southern China contains *Glossopteris indica* Feist. in association with *Cladophlebis rœsserti* (Presl.), a typical Rhætic fern-like plant. *Glossopteris indica* is also recorded from Kiang-ti-ho.

Tectonic Disturbances and Volcanism.

The Palæozoic of China closed in general with extensive withdrawal of the sea over wide areas. There were however, some tectonic disturbances as in other countries, though they do not appear to have been so pronounced. The most notable was the folding of the strata of the Tsingling geosyncline, this being shown by the relationship of the Palæozoic and Mesozoic strata in the present Tsingling range, as illustrated in the partial section from von Richthofen (Fig. 294, p. 406). The movement appears to have been from the north southward or from the old-land towards the geosyncline, as is the usual case in such folding. This is shown by the steeper limbs of the anticlines of the older series on the south, though subsequent (late Jurassic) folding has steepened these still more.

At this time too, there appears to have begun a period of deep-seated igneous intrusions which continued to Middle Jurassic time. This resulted in the formation of the granitic rocks of the Nanking Hills (see section Fig. 172, p. 250) and others like it, which did not extend above the Permian. Local metamorphism also took place during this interval, according to recent observations of Mr. C. C. Liu.

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APPENDIX.

SUPPLEMENT A.

ADDITIONS TO THE PALÆOZOIC STRATIGRAPHY OF CHINA AND ADJACENT REGIONS.

The rapid progress in the study of Chinese Palæozoic Stratigraphy makes it desirable to take account here of the new discoveries and interpretations, and thus bring the discussion, so far as possible, up-to-date. At the same time a few corrections are introduced here, and references to literature not previously available are given. The revised spellings of the names of geological formations, recently adopted by the Survey, are summarized at the end of the supplement.

Sinian System.

China. Beds of Sinian age have recently been discovered in the Yangtze valley by Professor J. S. Lee and students from the Geological Institute of the National University. These Sinian strata are especially well shown in the Ichang gorges where the Nant'ou tillite is followed by some 700 meters of limestones with characteristic *Collenia*, especially *C. cylindrica*. These are the beds previously referred to the Kisingling series by Willis and Blackwelder and by them considered to be of Cambro-Ordovician age. (See section given on page 20). These beds are succeeded by the Shipai shales of Lower Cambrian (Manto) age, characterized by *Redlichia chinensis*, etc. The Nant'ou tillite is now definitely included in the beds of the Sinian System, as suggested on p. 21.

The Sinian formations of the Ichang gorge region are susceptible of a three-fold division, this being in descending order:

Super Formation: Lower Cambrian Shipai shales.

SINIAN SYSTEM

Upper or Tongying Limestone..... .....510 m.
Middle or Tonshanto Series.....198 m.
Lower or Nant'ou Tillite Series..... 83 m.

Unconformity.

SUBFORMATION: Santoupin Group (Archæan?)

In view of this new discovery the diagram on p. 20 will have to be changed, the entire sedimentary series there represented being a part of the Sinian System.

INDIA AND THE HIMALAYAS: In India, the Archæan formations are succeeded unconformably by a series of little or not at all metamorphosed rocks which have been designated by the collective term *Purana Group*. In the Peninsula area they admit of the following subdivisions in descending order:

PURANA Group:

VINDHYAN SYSTEM

Upper Vindhyan

Bhander Series
Rewah Series
Kaimur Series

Disconformity

Lower Vidhyan

Kurnool Series } Limestones and calcareous shales
Rhima Series, etc. }
Malani Series, rhyolites and tuffs
Granite intrusion

UNCONFORMITY

CUDDAPAH SYSTEM

Upper Cuddapah

Nallamalai, Kirtna and Kaladgi Series

Disconformity
Lower Cuddapah
Bijawar, Cheyair and Gwalior Series
Papaghani Series
GREAT UNCONFORMITY.
ARCHÆAN GROUP.

The younger or Vindhyan System is correlated by the Indian geologists with the Torridonian of Great Britain, and the older or Cuddapah with the Algonkian. The former is undoubtedly referable to the Sinian System, to which the older may also eventually be found to belong, though the possibility of its pre-Sinian age may not be denied.

The Vindhyan system forms the central Indian Highlands, which divide the Indo-Gangetic plain from the Deccan plateau, extending from the Vindhya mountains on the west to the western part of Behar province on the east. They appear again in a belt of unfossiliferous sediments between the crystalline rocks of the Central, and the younger rocks of the Outer Himalayas, and these are believed to be the northern outliers of the strata of the Peninsula with which they were formerly continuous. If this was the case, they represent the deposits in a geosyncline of very great width, much wider than that of the present Indo-Gangetic plain. It it however, conceivable that the strata of central India were deposited in a geosyncline to the south of the former old-land now converted into the great alluvial plain, while those of the Himalayas were formed in the Himalayan geosyncline to the north of this old-land where subsequently the younger Palæozoic strata accumulated.

The Vindhyan system has a thickness of some 14,000 feet, and consists of strata all of which are probably of continental origin. At least no undoubted marine fossils have been found, though the

rocks are eminently fitted to preserve them. Those remains which have been obtained are some chitinous disks, probably of some crustacean or merostome, and "fucoidal" markings. The lower part of the Vindhyan series consists of limestones and shales with rhyolites and granitic intrusions, while the upper part is almost exclusively arenaceous, with ripple-marked and diagonally-bedded sandstones, and beds penetrated by mud-cracks, a characteristic feature. Except where affected by comparatively recent disturbances, the beds are still practically horizontal, and there is no metamorphism other than the normal induration. The shales have not developed cleavage, nor have the limestones undergone crystallization. A feature of some interest is the presence of diamond-bearing conglomerates between the several subdivisions, especially of the upper Vindhyan series. The diamonds are derived from pebbles of an older andesite, which is regarded as the mother-rock in which the diamonds crystallized.

The Vindhyan series rests unconformably upon the gently folded CUDDAPAH SERIES, or upon the much disturbed and altered ancient rocks. The beds of the Cuddapah series have a different distribution, being extensively developed to the south of the Deccan plateau, the type locality lying in the middle of the Madras presidency. These beds rest with a great unconformity upon the Archæan rocks but are themselves only moderately disturbed. They consist of much indurated and compacted shales, slates, quartzites and limestones, and although slatey cleavage is developed in the argillaceous rocks, more extreme metamorphism is lacking. The series has a thickness of 20,000 feet and the beds are totally unfossiliferous, though the rocks are well fitted to preserve organic remains. This would indicate that, like the younger Vindhyan, the Cuddapah is also a continental series. Much volcanic rock occurs, and dykes of basic augite-andesyte traverse the older rocks, these being regarded as the parent rocks of the diamonds. They are the source of the pebbles of the diamond-bearing

conglomerates of the younger series. The Cuddapah series, in spite of its moderate metamorphism, is probably of late Algonkian age and therefore pre-Palæozoic.

Cambrian System.

General. The three provinces of Lower Cambrian time in Eurasia (p. 22) were the Atlantic (*Holmia* fauna), the Boreal (*Olenellus* fauna) and the Indian (*Redlichia* fauna). The Indian province was probably in part continuous with the Pacific, the latter probably not being the home of the *Olenellus* fauna as previously suggested, that fauna being endemic in the Boreal waters. From this source it extended southward in the Appalachian geosyncline of eastern North America to the Albany axis (p. 60), which already existed in Cambrian time. *Olenellus* is found in the deposits north of this axis, but more rarely in the southern Appalachians where other forms occur which apparently had their home in the Pacific. The *Olenellus* fauna likewise extended south in the Cordilleran geosyncline of western North America, probably to a much greater distance than on the east. On the European side this fauna reached south to northern Scotland while in Asia it extended into the Irkutsk basin but was separated by land from the Indian extension (See map, p. 24).

In the southern Appalachians the Lower Cambrian fauna is characterized by "*Olenopsis*" *roddyi* Walc.* and other forms probably of Pacific origin, while the Lower Cambrian deposits of the southern Cordilleran geosyncline carry *Nevadia*, *Callovia*, etc., which probably also belonged to the Pacific Lower Cambrian fauna, and some of which extended into the Appalachian geosyncline. On the other side of the Pacific, in the Indo-Pacific region, the sea extended northward through China into Manchuria and westward along the Himalayan

* Probably not congeneric with *Olenopsis zoppii* Meneghini of Sardinia.

geosyncline. Here, as in the Australian region, it was characterized by *Redlichia* (map, p. 23).

In Middle Cambrian time the Boreal seas extended far to the south in eastern Asia and probably became confluent with the Indo-Pacific basin. In any case, the fauna has been traced as far as Tonking in Indo-China. In like manner the fauna extended southward in the Cordilleran trough of western North America and probably to a certain extent in the northern Appalachian trough. Like the *Olenellus* fauna, the *Olenoides-Dorypyge* fauna, was probably at home in the Boreal sea.

Late Middle or early Upper Cambrian of the Atlantic province extended in the Mediterranean embayment as far east as Syria (Blankenhorn VIII, 2, pp. 12-13).

China. One of the most significant recent discoveries in the Cambrian of China was made in the Ichang Gorge of the Yangtze by Professor J. S. Lee and students of the National University, who found the Sinian limestone succeeded by 200 meters of Lower Cambrian shale with *Redlichia chinensis*. This is the Shipai shale of the gorge section, and it begins 700 meters above the Nantou tillite and in general corresponds, in part at least, to the Manto shale of North China. This Lower Cambrian shale is in turn overlain disconformably by the Ichang limestone, the lower beds of which are characterized by *Archæocyathids* and *Girvanella sinensis*, and represent Lower Ordovician.

Evidence is accumulating to indicate the wide extent of the Cambro-Ordovician disconformity in China, this disconformity in the Ichang gorge cutting out Middle and Upper Cambrian, while in other parts of China the Ordovician is found to rest on various members of the Middle or Upper Cambrian series.

The latest studies of the Cambrian succession in China have shown the presence of a higher member of the series than was

previously recognized. This is the FÊNGSHAN SERIES which succeeds the Chaumitien limestone previously regarded as the highest member of the Cambrian (see section p. 33). In Fêngtien the SHAKUOTUN LIMESTONE appears to represent the lower part of the Fêngshan series and is followed disconformably by Ordovician or younger beds.

In the Kaiping basin of north Chihli, the Chaumitien limestone is replaced by the CHANGSHAN SHALE (Sun 55). This underlies the Fêngshan limestone and has in part a distinctive fauna. The Kushan shale (upper Middle Cambrian) is doubtfully represented, but the Changhia limestone (lower Middle Cambrian) and the Manto shale (Lower Cambrian) are present.

In Lincheng, south Chihli, the Lower Ordovician rests disconformably on the Kushan shale which here carries its characteristic fauna. The Changhia and Manto shales are also present, the latter resting disconformably on the Sinian.

In Shantung, recent studies by Mr. Sun have shown that the limestones of Pagoda hill or Kaoli-shan, opposite Taishan, represent a new and very young Upper Cambrian horizon (Kaoli limestone), essentially equivalent to the Fêngshan series of the more northern region. This limestone has furnished *Chlonograptus cambria* Sun and many brachiopods and trilobites, most of which are new. Very few of the species are at present known from other localities. Among the characteristic forms are the following (Sun 55). In the upper part: *Ptychaspis angulata* Sun, *P. subglobosa* Grabau, *Quadraticephalus walcotti* Sun, *Obolus taianensis* Sun. In the lower part: *Agnostus cyclopygeformis* Sun, *Taianocephalus grabaui* Sun, *Mansuya orientalis* (Grabau) Sun, *Kaolishania pustulosa* Sun, *Chuangia batia* (Walc.) and *Syntrophia orthia* Walcott.

From the upper beds of the limestones at Chau-mi-tien, Mr. Sun has obtained a fauna of Orthoceran cephalopods which appears to

mark the first invasion of the Ordovician fauna. These Orthocera are still associated with Upper Cambrian trilobites.

Ordovician System.

The Cambro-Ordovician disconformity appears to be a very general structural feature in the Chinese succession, the Lower Ordovician resting on various members of the Cambrian, even the Manto shale, as in the Ichang Gorges.

Graptolite Shales.

New Zealand. In Lower Ordovician time the Bengal Straits were apparently still open as they were in the Upper Cambrian period, for Ordovician graptolites of characteristic European and American types are found in New Zealand (north-west and south-west part of South Island). The fossils identified from Golden Ridge, near the West Wangami inlet, are only graptolites and comprise the following forms: *Bryograptus lapworthi* Ruedem., *Dichograptus octobrachiatus* Hall, *Didymograptus extensus* Hall, *D. gibberulus* Nicholson, *D. nitidus* Hall, *D. nanus* Lapw., *Goniograptus perflexilis* Ruedem., *G. geometricus* Ruedem., *Loganograptus logani* Hall, *Phyllograptus anna* Hall, *P. ilicifolius* Hall, *P. typus* Hall, *Tetragraptus amii* Elles and Wood, *T. bigsbii* Hall, *T. quadribrachiatus* Hall. They represent the Deepkill fauna of eastern North America being nearly all characteristic American species. The equivalent European horizon is seen in the middle Skiddaw slates of England.

China. Middle Ordovician graptolite shales have been discovered by Pères Teilhard de Chardin and Licent in the western Ordos, between Ningsiafu in Kansu and Tongkow, Mongolia, not far from the Great Wall. (Approximately longitude 107° E., Lat. 39° 20′ to 39° 30′ N.). These graptolites occur in a dark, fine, nearly black massive argillutite, which appears to be of considerable thickness and overlies the older Ordovician limestone. Several of these species

are new but one at least, *Didymograptus euodus* Lapw. indicates a lower Llandeilo horizon, as does also *Dicellograptus* sp. The two new forms are *Climacograptus teilhardi* Gr. and *C. licenti* Gr. named after the discoverers of these species. The first is represented by stipes up to 20 millimeters in length with a width of 2 millimeters at each end. There are 9 thecæ in 10 millimeters and they are almost opposite or but slightly alternating. The excavations are very oblique and crescentric, occupying about one-fourth the width of the polypary on each side. The lower part of each theca above the excavation is thickened in crescentiform manner, giving the surface a sculptured appearance. The outer angle of the aperture is acute and is also thickened by a short crescentiform ridge. The length of the outer free edge of the theca is one millimeter, the total length 2 millimeters, giving an overlap of about one-half the length. The thickening of the thecal margins, on either side of the excavation, gives the surface a distinctly sculptured appearance, which is very striking. The posterior thickening does not follow the margin of the excavation but, beginning at the ventral edge of the excavation, curves backward at a greater radius. The species is of the general form and proportions of *C. antiquus* but is readily distinguished by the sculptured character of the surface.

Climacograptus licenti Gr. is also represented by fragments something over 2 centimeters in length, these increasing from a width of one millimeter at the lower end to nearly 2 millimeters at a point 12 millimeters higher, after which there is a slight decrease again until the width of the upper end is only 1.5 millimeters. In the lower part there are 12 thecæ to 10 millimeters, in the upper only 10 to 10 millimeters. The excavations are oblique, approximately alternate in position and are wider at the rounded inner, than at the outer end. They extend inward for about 0.5 millimeters or one-third to one-fourth the width of the stipe. The outer angle of the aperture

is acute, sometimes slightly pointed. The species differs from *C. teilhardi* in the absence of the thickening of the margins of the excavations, and in having both sides of the excavations concave. They are also deeper in this species, occupying in some specimens more than one third the width of the stipe.

Graptolite shales of a higher horizon have been obtained by Mr. P. Yuan of the Survey from Kansu.* The formation which has furnished these is typically exposed at Kuan-Chuang, 20 li south-west of Ping-Liang-Hsien, Kansu, about latitude 35° 20′ N., longitude 106° 40′ E.** The formation, which has been named PINGLIANG SHALE, consists largely of compact, finely arenaceus, siliceous argillutites of a dark gray color, weathering brown, and splitting into layers a few millimeters to a centimeter or more in thickness. The graptolites are abundant and are generally well preserved, occurring often in relief and generally having a deep black color. The thickness of the beds cannot be ascertained, and they are disconformably succeeded by beds of Carboniferous (Taiyuan) age. The entire series is overturned on the north so that the Ordovician beds are on top. Preliminary studies of this graptolite fauna have shown it to comprise the following 12 species: *Climacograptus bicornis* Hall, *Cl. parvus* Hall, *Didymograptus sagitticaulis* Gurley, *D. serratulus* Hall, *Dicellograptus divaricatus* (Hall), *Nemagraptus exilis* (Lapw.), *N. gracilis* (Hall), *Dicranograptus* cf. *furcatus* (Hall), *D. clingani* Carruthers, *Diplograptus* (*Glyptograptus*) *angustifolius* (Hall), *D.* (*Gl.*) *teretiusculus* (His.) var. *kansuensis* Gr. (var. nov.), *Orthograptus whitfieldi* (Hall). These species indicate a late Middle Ordovician horizon,

* The first of these graptolites was collected by Mr. Yuan June 3rd, 1923, and to him, therefore, belongs the credit of discovering the first Ordovician graptolites in North China. Shortly after this, the graptolites previously noted, were found by Pères Teilhard and Licent in the Ordos, at a locality some distance north of the one discovered by Mr. Yuan.

** Details furnished by Mr. Yuan.

i.e., the horizon of the Glenkiln of western Europe and of the Normanskill of eastern North America. A remarkable feature of this fauna is its typical American character, this being especially shown by the abundance of *Didymograptus sagitticaulis* Gurley, a species which appears to be unknown in Europe but is characteristic of the Normanskill shales of eastern New York, Canada, Arkansas and British Columbia. Our specimens include fragments of the stipes 26 centimeters long but with a width of 2.9 millimeters at each end. The thecæ, which are inclined at angles of about 30°, are about 3 millimeters long and overlap for nearly two-thirds their length. They are about one-third as wide as long, the outer margin being gently concave and the apertural margin straight and forming acute angles with the outer margin. There are 7 thecæ to 10 millimeters. Smaller fragments, ranging in width from 1.5 to 1.8 millimeters, with 8 thecæ in 10 millimeters, and others 1.2 millimeters in width with 9 thecæ in 10 millimeters, appear to represent the more proximal portions of these stipes, agreeing with them in all other respects.

Climacograptus bicornis is abundant and shows the normal character of the species with well developed basal spines, which are generally very broad. *C. parvus* Hall shows a virgella 10 millimeters or more in length with a proximal portion nearly one millimeter in width and the lateral spines very inconspicuous. The sides of the thecæ are straight or very gently rounded, widest in the middle, while the apertures are straight or very slightly introverted, the excavations occupying three-eighths the width of the polypary, but less than one-fourth the ventral margin. The virgula is long and conspicuous, and there are 11 thecæ in 10 millimeters.

Glyptograptus terretiusculus (Hisinger) is represented by the new variety *kansuensis*. In stipes 20 millimeters long, the maximum width is 2.2 millimeters. while the virgula projects 20 millimeters, becoming thickened in its upper part. The virgella is 9 millimeters

long. The basal width of the polypary is .7 millimeters, the sicula is 1.2 millimeters long and .3 millimeters wide. The first theca has lateral spines, the normal length of the thecæ is 2 millimeters, the overlap being one-half the length, and the angle of divergence 30°. The excavation is horizontal, one-fourth to one-third the width of the polypary, the free ventral margin somewhat convex. The apertural angle is acute, often slightly mucronate. There are 9 thecæ in 10 millimeters, whereas the typical Welsh form has from 14 to 10 in 10 millimeters, the stipes being slightly broader. The excavations of our specimens are also more pronounced.

The other species found in this fauna are in all respects, of the types of those found in eastern North America, except *Dicranograptus clingani*, which is primarily a European form. It would appear that this fauna belongs to the northern basin of the Ordovician sea in China and that, like the *Actinoceras* fauna, of which it was practically a contemporary, it entered this basin from the Boreal region. This discovery requires a slight south-westward extension of the northern basin on the palæogeographic map (Fig. 29, p. 51).

Graptolites have a two-fold value to the stratigrapher. In the first place, because of their floating habit and consequent wide distribution, they form excellent and precise horizon markers. But they also serve to indicate the position of the shore line wherever they are found entombed in typical graptolite shales. The author and his former pupil, Dr. M. O'Connell, have called attention in 1917 to the fact that the character of the shales and the distribution of the graptolites indicated shore conditions rather than a deep water, as had been the prevailing opinion (IV, 14). Indeed it was conclusively shown that these graptolite shales are to be interpreted as deltas along the shores of the ancient sea. More recently Scupin (49) has come to essentially the same conclusion, this conclusion having apparently

been reached independently, for he seems not to have been familiar with our earlier paper.

Lower Ordovician Limestone.

Recent studies in Lunshan, near Nanking (pp. 96-97), by Messrs. Sen and Hsü of the South-Eastern University, Nanking, have shown that the limestone of that hill is of Lower Ordovician age instead of representing the Upper Ordovician, as previously supposed on the strength of the fossils listed by Frech. The lowest beds are intruded by the granite and are more or less mineralized. They are followed by crinoidal and later by cherty limestones and at the top by gray limestones which have furnished a number of fossils that have been submitted to me for study. These comprise two characteristic species of cephalopods, previously known only from the Lower Ordovician of North China, namely *Proterocameroceras mathieui* Grabau of the Peilintze limestone, and *Suecoceras attenuatum* Grabau of the Yehli limestone. As these fossils are found in the highest limestone stratum of the hill, we are confronted with the question as to whether the species obtained by von Richthofen, and identified by Frech with Upper Ordovician types (see *ante*), were wrongly determined or came from another locality. The *Proterocameroceras* beds are apparently disconformably succeeded by beds of early Silurian age but the contact may be a fault and the Upper Ordovician, which may be present elsewhere in this region, may be cut out in this section. According to Mr. Sen the hill is one limb of an anticline, and higher beds may still be present elsewhere. The Lunshan limestone must, however, be regarded as of Lower Ordovician age. As previously noted, some beds of this limestone are rich in *Girvanella sinensis* and this form is probably to be regarded as an index fossil of the Lower Ordovician of the southern waters. The cephalopod fauna, however, belongs to the northern type and indicates the southern extension of the northern faunal province to the Yangtze.

In the Ichang gorge of the Yangtze, the Lower Cambrian Shipai shales with *Redlichia*, are disconformably succeeded by the ICHANG LIMESTONE 1250 to 1680 meters in thickness (Lee 37). This, with the Lower Sinian limestone, was classed as Kisingling limestone by Willis and Blackwelder and considered of Cambro-Ordovician age. The lowest beds of the Ichang limestone have furnished *Girvanella chinensis* and *Archæocyathids* apparently of types also found in the limestone above the *Redlichia* beds in Australia. These Archæocyathids probably belong to the southern type of the older Ordovician fauna and mark the invasion, at the opening of the Lower Ordovician, of the Indo-Australian fauna through the Bengal Straits, which were still open, and through which likewise passed the graptolites previously noted.

In Australia the Archæocyathid limestone rests probably with a disconformity on Lower Cambrian beds with *Redlichia** and may also represent Lower Ordovician rather than Cambrian as has generally been held.

The higher beds of the Ichang limestone have furnished *Callograptus* cf. *salteri* Hall, a species characteristic of the lower Deepkill of eastern North America, and of the lower Arenig of Great Britain. The question whether or not a part of this thick limestone series is to be regarded as late Cambrian, must for the present remain undecided, but the occurrence, near the base, of *Girvanella sinensis*, a form widespread in the Ordovician of southern China, argues for a Lower Ordovician age. If the Australian Archæocyathid limestones are Cambrian, these beds may also represent that horizon.

Beds apparently of the same age have been found by Mr. T. C. Wang of the Survey, at Hêng-lu-pu, north of Wu-Ning city, northwest Kiangsi. These constitute the Wushimên limestone, 450 meters

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* See the section by Walter Howchin reproduced in Haug, Traité, p. 608.

in thickness, which may be in part of Cambrian age. The upper, thin-bedded argillaceous limestones have furnished *Dendrograptus* cf. *persculptus* Hopk., an Arenig form of Great Britain.

Higher Ordovician.

The Ichang limestone of the Yangtze Gorge is disconformably succeeded by the NEICHIA SHALES with the characteristic fauna previously described (p.93 et seq.). This shale is followed conformably by the PAGODA LIMESTONE which abounds in *Orthoceras chinensis* (Fig. 64, p.93) and furnishes the well-known ornamental "Pagoda stone" of the Yangtze region. The Neichia and overlying Pagoda beds have a combined thickness of about 80 meters (Lee). They are disconformably followed by the Lungma graptolite shales of Lower Silurian age.

SILURIAN SYSTEM.

Fossiliferous strata of Lower Silurian age are found to be wide-spread in central China. The fauna entered the Chinese basin through the Himalayan geosyncline, passing north along the west Yunnan-Szechuan geosyncline and spread in the Tsingling geosyncline as far east as the Nanking hills region of today. It was represented partly by a trilobite and brachiopod facies, partly by a pelecypod facies and, in certain sections where deltas of mud were forming near the shore, it is represented in the graptolite facies. In eastern Yunnan we find only the overlapping beds of the Silurian resting upon the older rocks, in most places only the higher members being present. A correction is necessary here to the statement made on page 126 in the description of the Mientien group, the highest member of the Lower Silurian in eastern Yunnan. This is characterized by *Lingulella cuneatiformis* Grabau and *Modiolopsis crypta* Grabau, as well as ostracods, but not by *Spirifer bourgeoisi* Mans. and *Leperditia* as there stated, these belonging to the succeeding Miaokao group of Upper Silurian age. Older beds than the Mientien group are also

found in eastern Yunnan, these carrying *Favosites*, *Syringopora*, etc. At Si-Yang-Tan, east Yunnan (p. 127), the *Spirifer bourgeoisi* beds, formerly referred by Mansuy and Deprat to the Ordovician, belong to the Upper Silurian (Miaokao group) or Monroan, not to the Niagaran.

The lowest Silurian beds so far discovered in China, are found at Lunshan, one of the Nanking hills, where they rest disconformably upon the Lower Ordovician Lunshan limestone. They have been named the KAOCHIAPIEN SHALES (Liu) and consist of yellow argillaceous shales in the lower part, carrying trilobites, among which *Cheirurus lunshanensis* Grabau (Fig. 295), *Callymmene* sp., *Proetus* sp., and *Phacops* cf. *chinensis* Reed have been identified. The latter is a form which was first found in the upper Namhsin or Kônghsa marls of Burma, a horizon much higher than the trilobite beds of Lunshan. The Lunshan *Phacops*, provisionally referred to the Burma species, may prove to be distinct when further material is available. With these trilobites occurs a very finely annulated *Orthoceras* with three or four annulations in one millimeter (*O. hsui* Grabau).

Fig. 295.

Cheirurus lunshanensis Gr. Pygidium × 4. Kaochiapien Shale, Lunshan.

These trilobite beds lie only a few meters above the contact with the Lower Ordovician Lunshan limestone, though this contact, as before noted, may possibly be a faulted one. Higher up, in the shale series, graptolite beds were discovered by Professor K. Weiman Hsu of South-Western National University, who also found the trilobites in the lower beds. These graptolite beds may be the same as those previously recorded from this locality by Frech (pp. 129 to 130). From them the following species have been obtained, only a few of which, it will be noticed on comparison, had previously been

recorded by Frech: *Climacograptus scalaris* (His.) var. *normalis* Lapw., *C. törnquisti* Elles & Wood, *C. medius* Törnquist, *Glyptograptus incertus* E. & W., *Monograptus incommodus* Törnquist.

These graptolites indicate the lower Birkhill (Lower Llandovery) horizon of Great Britain. The zone is probably to be correlated with the graptolite beds of the Pangshapye stage of Burma (see *ante*, pp. 118-119).

What is probably a slightly higher horizon is represented by the LUNGMA GRAPTOLITE SHALE of the Ichang gorge on the Yangtze (Lee 37), a horizon included in the Sintan shale by Willis and Blackwelder. The series consists of black shales with the graptolites in a good state of preservation. Preliminary identification has given the following list: *Petalograptus palmeus* (Barr.) (Fig. 296 c, d), *Monograptus sedgewicki* (Portlock), *M. regularis* Törnquist, *M. clingani* (Carruthers), *Glyptograptus incertus*, *Diplograptus* (*Cephalograptus*) *cometa* (Geinitz) (Fig. 296 a, b). The age of these beds is still to be considered as Lower Silurian, though they may represent early Upper Llandovery of Great Britain. They apparently represent the *Monograptus sedgewicki* zone (Zone 7, p. 115) and the *Cephalograptus cometa* zone (Zone 6, p. 115). Only one species, *Glyptograptus incertus* appears to be common to this horizon and the graptolite shales of Lunshan, and the Lungma

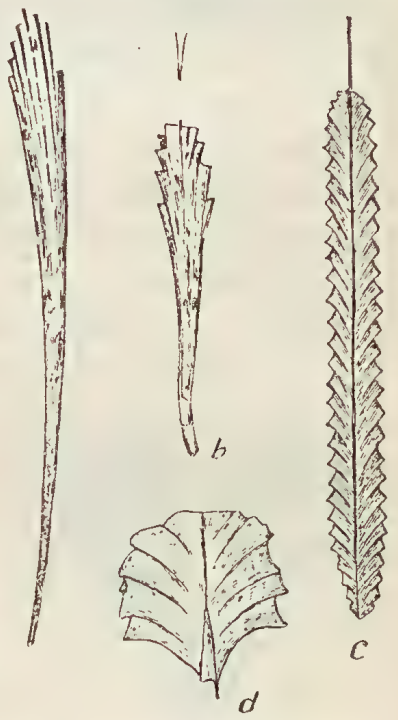

Fig. 296.

Silurian Graptolites, Lungma shale. *a*,–*b*, *Cephalograptus cometa* (Geinitz); *a*, typical specimen × 3; *b*, distal fragment showing virgula × 3; *c*,-*d*, *Petalograptus palmeus* (Barr); *c*, complete specimen reverse aspect × 3; *d*, sicula and early thecæ much enlarged. (After Elles & Wood).

beds must be regarded as representing a higher horizon than the shales of Lunshan.

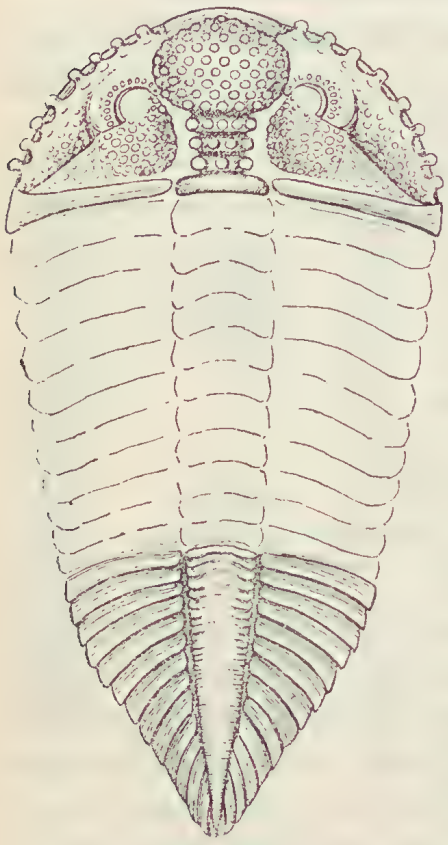

Fig. 297.

Encrinurus (*Coronocephalus*) *rex* Gr. Restored from cranidia, free cheeks and pygidia - thorax unknown - × 2. Fuchih shale.

In south-eastern Hupeh (Pl. V sect. II) Messrs. C.C. Liu and C.Y. Hsieh found Silurian beds resting disconformably upon the late Ordovician limestone (Tafan limestone) with *Orthoceras chinensis* in the upper part, and representing the Pagoda limestone beds of the Yangtze gorges. The Silurian beds were named by them the FUCHIH (FUCHIHKOU) SERIES, which consists of three parts. The lower comprises mainly gray-yellow, thin-bedded shales, the middle an alternation of yellow shale and gray sandstone, while the upper part consists mainly of sandstone which is sometime quartzitic and conglomeritic The lower and middle parts have an aggregate thickness of 800 to 1000 meters, while the upper sandstone is only from 50 to 100 meters thick. In the Yang-Sing district the lower yellow and green shales contain a fairly rich fauna among which *Encrinurus* (*Coronocephalus*) *rex* Grabau is the dominant form (Fig. 297). With it occurs *Proetus latilimbata* Grabau, *Spirifer hsiehi* Grabau (the same form identified by Kayser as *Spirifer elevatus* Dalm. from the Chaotien limestone of the Tsingling region (p. 132)) and some other brachiopods. The upper sandstone is

unfossiliferous and may be the westward extension of the Wutung quartzite of the Nanking hills, Kiangsu. This sandstone is disconformably succeeded by the lower Yangsing limestone of Lower Carboniferous (Dinantian) age.

Yellow shales and sandy beds with *Proetus latilimbata* Grabau, and apparently representing the same Silurian horizon, have also been found by Mr. Hsieh in north-west Hupeh.

Essentially the same series of Silurian strata has been discovered by Mr. T. C. Wang of the Survey in north-western Kiangsi (sect. III) but they appear to have a much greater thickness there, resting disconformably upon the Wushihmên limestone which contains *Dendrograptus* cf. *persculptus* Hopkins and is apparently of Lower Ordovician age. Mr. Wang has found a great series of yellow-red and green shales with intercalated thin beds of sandstone to which he has given the name of YAISHAN FORMATION, and which has a thickness of about 2500 meters. About 300 meters below the top he has discovered a rich fauna, which is again characterized by *Encrinurus* (*Coronocephalus*) *rex* Grabau, and is apparently the equivalent of the lower shales of the Fuchih series of south-western Hupeh. With this trilobite occur *Spirifer hsiehi*, *Leptæna distorta*, and other fossils (Locality 1118). A somewhat lower horizon (Locality 1117) is rich in pelecypods, among which the following forms may be especially noted: *Orthonota antelonga* Grabau (sp. nov.) allied to *O. perlata* Barr. of Etage E but with proportionally longer anterior, and more regularly rounded posterior end; *Modiomorpha wuningense* Gr. (sp. nov.), and *Aviculopecten cybele* Barr. var. *acuta* Gr. (var. nov.) differing from the Bohemian (Etage E) form in the more acutely projecting wing.

The fauna, as a whole, suggests a rather early Silurian horizon and it must at present remain a matter of doubt whether the entire series of the Yaishan formation belongs to this horizon or

whether a part of the lower series is of Ordovician age. The fact that these fossils occur in the upper part of the formation, whereas in south-west Hupeh they occur in the lower part of the series, which there rests disconformably on the Upper Ordovician, might suggest that a part of this shale is of Late Ordovician age. On the other hand, it is not improbable that the characteristic trilobite, *Coronocephalus rex*, ranges through a very extensive series of strata and that therefore the entire formation is to be regarded as of Silurian age. It is disconformably succeeded by the Tsoshan limestone, which is in part of Lower Carboniferous age and appears to be the precise equivalent of the Yangsing of Hupeh.

The Wutung Quartzite.

In the consideration of the mid-Palæozoic history of eastern China, the Wutung quartzite (previously called Wutungshan quartzite) becomes a feature of stratigraphic significance. Originally it was referred by von Richthofen to the Devonian, but on page 250 of this work, the suggestion was made that its age is more probably early Dinantian. A recent expedition to Ch'i-Hsia-Shan, near Nanking by a Survey party* gave an opportunity for closer study of this quartzite, as well as the overlying Chihsia limestone. There can be little doubt that the Wutung quartzite underlies the Chihsia limestone disconformably for, though the contact was not actually seen, the formations were traced within a few feet of each other, and it was found that there is absolutely no intercalation of beds, but that the quartzite is abruptly succeeded by the limestone. This of course indicates a pronounced change in sedimentation from continental to marine conditions, and probably at least a partial consolidation of the quartzite before the Viséen sea transgressed over it. Otherwise, there would

* The party included Dr. W. H. Wong, Director of the Survey, Mr. C.C. Liu, the Survey's representative in Kiangsu province, Mr. Y. M. Hsü, provincial geologist of Kiangsu and the author.

certainly be a moderate amount of reworking and the inclusion of sand grains in the lower part of the limestone. The latter begins with beds formed almost completely of calcareous algæ (*Girvanella?*).

From these facts it may be concluded, that the age of the quartzite is considerably greater than Lower Carboniferous. I do not believe that it should be referred to the Devonian for we have no evidence of Devonian sedimentation until we come to the western part of the Tsingling geosyncline and the south-western region of China in general, where marine Devonian beds are found. It is most likely that east-central China was a region of erosion in Devonian time, as was north China. If this inference is correct, the quartzite must be referred to the Silurian, and here the evidence from other regions is not conflicting. As we have seen, the Silurian Fuchih series of Hupeh has a thickness of 1000 meters and passes into sandy beds in its upper part. The Silurian shales underlying the Wutung quartzite in the Nanking hills region, are comparatively thin, probably not over a few hundred meters in thickness, and hence it is not at all improbable that this quartzite may represent the later sedimentation, in this region during Silurian time (probably Lower Silurian or Niagaran) while marine sedimentation was still continuing in the region further west (Hupeh and Kiangsi).

The quartzite is a purely continental formation and its induration is entirely due to secondary deposit of silica, while in some sections, notably in Chi-Hsia-Shan, it has still much the character of a sandstone, being extensively quarried there for mill-stones, as well as building purposes. Many small grottoes have been hollowed out in it in the vicinity of the temple and are now occupied by statuary. In this section the quartzite is not infrequently a pebble rock with pebbles of pure quartz up to the size of a bean or even larger. The grains are for the most part of irregular size and the cross-bedding is of the torrential type. Near the temple, where the quartzite beds are

vertical, determinations have shown that the original inclination of the diagonal layers was southward, approximately south 20° east, and their angle of inclination from 20 to 25°. This would indicate that the supplying streams came in general from the north, which is quite con istent with the palæogeographic conditions that had obtained in this region. As we have seen, mud deltas with stranded graptolites were formed in this region in early Silurian time, this indicating that it was a near-shore area. These mud deltas were apparently replaced by the sand deltas and river-flood plain deposits, which advanced over them, pushing the sea shore gradually westward and southward, the streams depositing these deltas coming from the north, the east and possibly from the south-east as well. It is quite within the range of possibility that the higher sands of the Hupeh Silurian section are the direct continuation of the higher part of the Wutung quartzite, the continental and marine beds having the relationship of replacing overlap with westward advancing continental deposits. If this is the relationship, the Silurian shales and quartzite beds of the Nanking region, if found in contact, should show a certain amount of interbedding, the one with the other, and a more or less gradual change to the continental conditions. Such interstratification has actually been noted in some regions by Mr. Liu. The Wutung quartzite has been recognized again in southern Anhui, where it is followed by the Chihsia.

Devonian System.

According to Yabe (65) the oft-quoted finding by Gottsche of a specimen of *Spirifer verneuili* in the province of Ise, Japan, referred to on page 170, is erroneous. These specimens came from China and consequently up to the present, no marine Devonian is known in Japan. This may further imply that the opening of the Mongolian geosyncline to the Pacific ocean in the palæogeographic maps (Fig. 109, p. 168 and Fig. 114, p. 171) did not exist.

DINANTIAN SYSTEM.

YANGTZE VALLEY. The recent study of the Chi-Hsia-Shan section, which is taken as the type section of the central Chinese Viséen deposits, has shown that in this hill no higher formations are present. The hill has a double character due to the fact that the entire series is repeated by faulting. The structure shown in the section Fig. 171 on page 249 is erroneous, the depression at 5 being due to the fault line. Beginning on the south we have the Wutung quartzite dipping gently to the north at first, and exhibited in its

Fig. 298. *Fusulinella gigas* Mans., top and end views × 4. (After Mansuy); a common Foraminiferan of the Chihsia limestone.

entire thickness in numerous quarry openings. Approaching the temple in the depression between the two parts of the hill, we find the dip to become steeper and the quartzite is succeeded by the steeply dipping Chihsia limestone, of which some 20 to 30 meters are exposed. The lower beds are compact limestones, frequently a calcilutyte, and sometimes largely formed of calcareous algæ (*Girvanella?*). The succeeding beds are coarser-grained and abound in corals among which *Syringopora*, *Fistulipora*, and *Michelinia* predominate (see p. 250 et seq.). *Amplexus spinosus* var. *sinensis* Grabau and *Lonsdaleia sinensis* Girty are other characteristic corals. Finally an abundant and very characteristic fossil is *Fusulinella gigas* Mans., a

species previously described by Mansuy from Yunnan. This is often weathered out upon the surface and reaches a diameter of 11 mm. (Fig. 298). The limestone is terminated by a fault, which is apparently a strike fault, and along which the valley between the hills is cut. Behind the temple, the quartzite appears again in its characteristic facies, showing cross-bedding. This portion is extensively hollowed out into small grottoes and shrines. The hill beyond this is again formed of the quartzite, which is often conglomeritic (No. 3 of section, p. 249). On the southern slope of the second hill, the limestone is again seen overlying the quartzite and carrying the same fauna. As before, it begins with beds rich in calcareous algæ followed by coarser-grained limestone with the characteristic corals before-mentioned, and abounding in *Fusulinella gigas*. A second fault again brings the quartzite to the surface, thus forming the remainder of the hill.

The Chihsia limestone has been found by Mr. Sun in southeastern Anhui, in Hochou Hsien at Ki-Lung-Shan (loc. 721). Here it is of a cherty character and contains the characteristic corals as well as *Fusulinella gigas*.

In southern Anhui Messrs. Yih and Li found the Chihsia (Yehshan) limestone and Wutung (Tongkwan) formation in Chinghsien, vicinity of Kufengchien. The Wutung is a quartzite about 100 meters thick while the Chihsia is a cherty limestone ranging from 0 to a little over 200 meters in thickness. Fossils have been found near the middle, these including (loc. 722), among other typical Chihsia fossils, the coral *Michelinia favositoides* Girty, a species originally described from the base of the Gorge limestone (Wushan) of the Yangtze.

The limestone frequently thins away, being overlapped by the coal series or higher Permian bed. The Chihsia limestone is

disconformably succeeded by limestones of Permian age (see beyond), which in turn are followed by the coal series.

It is still a matter of doubt whether the Sintan shale of the Yangtze gorges includes beds of Lower Carboniferous age. The probabilities are that this shale, together with the Lungma shale beneath it, represents the Silurian, which in other parts of Hupeh province has been found to have a thickness of 1000 meters. The combined thickness of the Sintan shale and Lungma shale of the Ichang gorge is about 600 meters. Following this disconformably with locally, however, a slight difference in dip, is the great Wushan limestone of Willis and Blackwelder, the lower part of which includes Lower Carboniferous beds, though the higher part is of Permian age. From basal members of the Wushan limestone a number of corals have been obtained by Professor Lee and students. These include *Lonsdaleia chinensis* Girty, *Pseudolonsdaleia lecí* Grabau, *Zaphrentis* sp. and *Michelinia favositoides* Girty. It is probably from this horizon that the corals described by Frech were obtained by von Richthofen (see *ante* p. 251).

Throughout east-central China, the Chihsia limestone lies directly and disconformably upon beds of Lower Silurian (Niagaran) age. Generally, in the more easterly occurrences, these Silurian beds terminate with a quartzite of which the Wutung quartzite of the Nanking region is believed to be the most extensive development, this gradually thinning away westward and southward from the region of the Nanking Hills.

The Chihsia limestone with its typical fauna of Viséen corals, etc. is now known from a number of localities in eastern central China. These may be briefly summarized.

Province	Locality and Number	Local Name
Kiangsu	Nanking Hills (602-605) (615-619)	Chihsia L.

Anhui	Hochou (721)	Chihsia L.
,,	Tung-Ling-Hsien (Yeh Shan) (702)	Yehshan L.
,,	Chinghsien (716)	Chihsia L.
,,	Tso-shan, Su-Sung-Hsien	Tsoshan L. (Lower)
Kiangsi	Te-Hua-Hsien (1120)	Tsoshan L. (Lower)
,,	Jui-Chian-Hsien (1121)	,, ,, ,,
,,	Hsui-Shui-Hsien (1122)	,, ,, ,,
Hupeh	Yang-Sing-Hsien	Yangsing (in part)
Hupeh	Ichang Gorge of Yangtze	Wushan (lowest part)

We may summarize the characteristic fossils of this limestone so far as known. (Those preceded by an asterisk (*) have so far been obtained only from the base of the Wushan limestone).

ALGÆ: *Girvanella nankingense* Grabau

FORAMINIFERA: *Fusulinella gigas* Mansuy

CORALS: *Syringopora ramulosa* Gold.
S. geniculata Phill.
Fistulipora minor McCoy
* *F. waageniana* Girty
Michelinia favositoides Girty
M. favosa Goldf. var.
Amplexus spinosus var. *sinensis* Grabau
Siphonodendron sp.
Lonsdaleia chinensis Girty
* *Pseudolonsdaleia lcei* Grabau
Zaphrentis delanoui E. & H.
Z. guerangeri E. & H.

BRYOZOA: * *Geinitzella chinensis* Girty

BRACHIOPODA:
* *Spirifer blackwelderi* Girty

There are some other brachiopod shells which have not yet been determined, but on the whole, the fauna presents a coral facies with Girvanella beds in the basal portion.

North-West China—Kansu. The Chihsia may be regarded as the coral facies of the Chinese Viséen. There is, however, another facies characterized chiefly by brachiopods, which is well developed in western China, especially in Yunnan and Kweichou (Weining formation) and in Kansu. Its occurrence in the latter province, especially on the Bardoun river and at Santachien, has already been referred to (p. 252). More recently, Mr. Phillip Yuan of the Survey,* has made an extensive study of the Carboniferous formations of Kansu and has brought back large collections of fossils from the Dinantian, as well as higher horizons. These have not yet been studied in detail and only a partial list can be given, this, however, showing that the Viséen is represented in the typical brachiopod facies. The Viséen is here called the Choniukou formation from the locality where it is best developed 70 li (18 miles) W. by S. from Wu Wai (Liang-Chow-Fu) (Long. 102° 44′ E., Lat. 37° 41′ N.). It is preceded by a continental formation with plant remains, which rests unconformably upon the pre-Cambrian Nanshan series. These continental sands and shales have a thickness at Cho-Niu-Kou, Wu-Wai-Hsien, of 67 meters. They and the higher beds have been folded and now strike N. 60° E., dipping 50° to 60° to the north-west. The Choniukou marine formation has a thickness of 68 meters and consists of limestones and shales, all of them abounding in marine fossils. Brachiopods predominate but corals occur at certain horizons, the most common being species of *Lithostrotion* and *Zaphrentoid* forms. *Productus giganteus* is well represented at several horizons by large and characteristic shells, these probably including one or more varieties.

* The details for the summary of these beds here given were kindly furnished by M. Yuan.

The fauna on the whole is of European facies and indicates close intercommunication between western Europe and north-western China at this period. Among the species so far determined the following may be mentioned: *Lithostrotion portlocki* (Bronn), *Productus giganteus* Martin, *P. giganteus* var. *edelburgensis* Phill, *P. tenuistriatus* Vern., *P. punctatus* Mart., *P. elegans* McCoy, *P. semireticulatus* Mart., *P. undatus* Defr., *Spirifer striatus* Mart., *S.* cf. *pankouensis* Gr., *Schizophoria resupinata* Mart., *Rhipidomella michelini* l'Ev., *Leptæna analoga* Phill., *Athyris royssi* l'Ev, and *Phillipsia kansuensis* Loczy.

The Viséen beds of the Choniukou section are followed with apparent conformity by 5 meters of sandstone carrying only plant remains and indicating a change to continental conditions. These beds are in turn succeeded by 15.5 meters of fossiliferous shales and limestones carrying the Taiyuan fauna and they in turn are followed disconformably by beds of lower Permian age. As we proceed in a westerly direction from Cho-Niu-Kou, the Viséen gradually disappears and is finally overlapped by the Taiyuan series, as will be more fully shown in the next section.

South-West China—Yunnan. In the Salween and Mekong valleys of western Yunnan (Coggin Brown 8) the Dinantian limestones and calcareous shales are always found in close association with the older metamorphosed Palæozoic limestones, which they unconformably overlie. At Fang-ma-ch'ang (99° E., 25$_0$ 5′ N.) these beds contain an abundance of Bryozoa, viz: *Hemitrypa sinensis* Reed (sp. nov.), *Polypora* cf. *fastuosa* de Kon. and *Rhombopora* sp. which Reed (45) refers to the Dinantian.

At Ta-shih-wo, 17 miles east of the Salween (Long. 99° 12′ E., Lat. 25° 5′ N.) the Viséen is very fossiliferous. The series consists of a higher coarse-textured limestone 200 feet thick and a lower finer grained one 60 feet thick, the two being separated by shales and limestone bands about 40 feet thick. The lower limestone

contains caves, being massive, slightly bituminous and fossiliferous. This is the horizon from which Loczy obtained *Productus yunnanensis* Loczy (Fig. 168, p. 245), *P. elegans* McCoy, *Zaphrentis beyrichi* Rothpl., etc., referred to above (p. 247) as of Viséen age. Coggin Brown obtained a more extensive collection from these rocks, which were identified by Reed (45) who lists the following species: FORAMINIFERA: *Nodosaria* sp., *Reniera* sp.: ANTHOZOA: *Syringopora intermixta* Reed (sp. nov.), *Amplexus* sp., *Campophyllum* cf. *caninoides* Sibly, *Caninia* aff. *nikitini* Stuck., *C.* aff. *lonsdalei* Keys., *Cyathophyllum fraternum* Reed (sp. nov.), *C. sororium* Reed (sp. nov.), *Fischerina insolita* Reed (sp. nov.), *F. solitaria* Reed (sp. nov.), *Rhodophyllum elusum* Reed (sp. nov.), *Histiophyllum occultum* Reed (sp. nov), *Cyclophyllum* sp.; BRYOZOA: *Fenestella* aff. *laxa* Phill., *Glauconome* aff. *bipinnata* Phill., *Rhombopora* cf. *bigemmis* Keys.; BRACHIOPODA: *Orthis* (*Rhipidomella*) *michelini* Lev., *O.* (*Schizophoria*) aff. *resupinata* Mart., *Schellwienella crenistria* (Phill.), *Leptæna analoga* Phill., *Productus yunnanensis* Loczy, *P. yunnanensis* var., *P. cora* d'Orb. var., *P. longispinus* Sow., *P. muricatus* Phill. var. nov. *paucispinosa* Reed, *P.* (*Pustula*) *impersonatus* Reed (sp. nov.), *Chonetes* cf. *crassistria* McCoy, *C. papilionacea* (Phill.), *Spirifer bisulcatus* (Sow.) var. *trigonalis* Mart., *S. bisulcatus* var. *kleini* Fischer, *S. duplicicosta* Phill. var., *S. tornacensis* de Kon., *S.* aff. *calcaratus* McCoy, *Spiriferina cristata* Schloth. ?; TRILOBITA: *Phillipsia spinifera* Reed (sp. nov). Reed refers this fauna to the Lower Carboniferous, i.e. Dinantian.

The presence in this list of *Spirifer tornacensis* would suggest Tournaisian, but the bulk of the evidence points to a Viséen age of these strata. About 20 miles further north-east, near the Lolo village of Sow-wa-shu (approx. Lat. 25° 20′ N., Long. 99° 10′ E.) beds of bluish banded limestone, striking 10° north-west, and with a vertical dip, have furnished a small fauna of corals (*Zaphrentis*, *Bothrophyl-*

lum, *Campophyllum* and *Syringopora* of undeterminable species), crinoid stems, mollusca and brachiopods. The latter include *Schellwienella crenistria* (Phill.), *Schizophoria* cf. *resupinata* (Mart.), and *Productus yunnanensis* Loczy (?) on the strength of which these beds are referred by Cowper Reed to the Dinantian.

So far as we are now able to judge, the horizons represented in western Yunnan between the Salween and the Makon, are the Dinantian and the Middle Permian (see beyond). The former rests unconformably upon the older limestones (Ordovician, etc.) and is followed disconformably by the Middle Permian. In this region there seems to be no representation of the Taiyuan series, though this may occur. Middle and Upper Carboniferous, however, seem to be entirely wanting.

In the area enclosed by the great elbow of the Yangtze, N.E. of Talifu lake and west of the southernmost point of the Yunnan-Szechuan border, the Dinantian rocks are found in contact with the Permian Red Beds. These Dinantian beds rest apparently upon Devonian which is exposed 4½ miles from Chin-Chiang-Kai (approx. Long. 100° 35′ E., Lat. 26° 10′ N.) (Reed 45, p. 315). The Dinantian beds are exposed in the vicinity of Ta-lu village (大路) (Long. 100° 52′ E., Lat. 26° 35′ N.) which lies on a horizon apparently low down in the Red Bed Series. The Dinantian rocks consist of alternations of soft light-colored shales and sandstones with bands of coarse, friable, yellow sandstones, and a hard white sandstone which forms cliffs. Some thin beds of white marly limestone also occur. The fossils obtained from beds of this series comprise, according to Reed (45 p. 317): ANTHOZOA: *Syringopora mekongensis* Reed (sp. nov.); BRACHIOPODA: *Reticularia indica* Waag. var. nov. *yunnanensis* Reed; OSTRACODA: *Leperditia viator* Reed (sp. nov.), *L. okeni* Munst. var. *intumescens* Reed (var. nov.), *L. subæqualis* Reed (sp. nov.), *L.* sp., *Bairdia* cf. *mucronata* Reuss.

These beds are succeeded by the Permian Red Bed series, which in this region begins with a coarse basal conglomerate. In the Talu region the conglomerate contains almost nothing but pebbles of limestone of the Dinantian or Permo-Carboniferous horizons. The pebbles are large and appear not to have traveled far.

In the region around Yunnanfu, Dinantian strata rest upon, or are faulted against, Cambrian or older formations. About 25 miles east of Yunnanfu, Dinantian beds are found in the mountain ranges which run north from the neighborhood or Yang-Tsung Lake (Coggin Brown 7, p. 103). These beds are exposed in the lower part of precipitous escarpments, the upper portion of which is formed by beds of Permian age. Brown originally referred these lower beds to the Middle Carboniferous, but from the study of the fossils collected by Brown, Reed (45, p. 317) has determined them to be of Lower Carboniferous age. Brown gives the following succession at Si-yang, the northernmost point at which coal is worked in these beds, in descending order:

h. Hard, grayish limestone
g. Bluish dolomitic limestone
f. Grayish, sandy shale with coal seams
e. Yellowish dolomitic limestone
d. Greenish shale
c. Thin limestone bands
b. Red shales
a. Limestones.

From Si-yang (Long. 103° 9′ E., Lat. 25° 6′ N.) the following species have been identified by Reed (45) from these beds. ANTHOZOA: *Michelinia siyangensis* Reed (sp. nov.); PELECYPODA: *Dysodonta deprati* Mans., *Parallelodon* cf. *obtusus* (Phill.), *Edmondia* aff. *goldfussi* de Kon.

There are two coal seams in this series the upper of which is five feet and the lower between seven and eight feet thick.

These beds are again well developed in a synclinal fold bounded on the east by the fault which forms the western shores of Lake Yangtsung. Near the abandoned coal mine of Hoshuitang (Long. 103° E., Lat. 24° 57′ W.) the following succession was determined by Brown (7, p. 106) in decending order:

i.	Limestone with corals	Thin
h.	Bluish white shales	
g.	White calcareous sandstone	
f.	Coal seam	
e.	White sandstone	
d.	Hard porcellaneous limestone	100 ft. approx.
c.	Dolomitic limestone	
b.	Decomposed andesitic lava flow	50 ft. approx.
a.	Red sandstone	Base not seen

The following species have been recorded, mostly from bed (i) by Reed (45, p. 317): FORAMINIFERA: *Textularia* sp , *Bigenerina* sp., *Trochammina* sp.; ANTHOZOA: *Chætetes subradians* Mans.? (hor. c. & d) *Rhodophyllum*? sp., *Histiophyllum*? sp., *Clisiophyllum* sp.

According to Deprat, the coral limestone (i) is overlain by a further 600 feet of limestones which contain a rich gastropod fauna, these being apparently the Loatien and Choueitang limestones of Deprat and Mansuy (see pp. 243 and 292). *Fusulinella gigas* Mans. (Fig. 298), characteristic of the Chihsia limestone, abounds in the Choueitang limestone. Above these the gray limestones of the lower Uralian of Deprat are found.

The beds designated by Deprat as Uralian may be of that age or they may represent an invasion of the southern sea in early Permian time, while the European waters invaded north China, and the Shansi series was formed (see beyond under Permian).

So far then as our present knowledge permits us to judge, the Dinantian is well represented in the Yunnanfu region by beds of Viséen age, older Dinantian being doubtfully represented if not absent. These Viséen beds appear to be conformably followed by beds of the age of the Taiyuan series (see below), and above these occur some local limestones which either represent the Taiyuan, or are of early Moscovian age. Typical Moscovian is not known, and the doubtful beds are succeeded disconformably by beds probably of Lower Permian age (see below).

Mongolian Geosyncline. From the Gasimursk range in eastern Transbaikalia a small Lower Carboniferous (Viséen) fauna has been listed by Fredericks (17, pp. 22-23). This includes: *Productus semireticulatus* Mart., and var. *gasimurensis* Freder., *P.* cfr. *burlingtonensis* Hall., *P. brachitheurus* Sow., *P. granulosus* Phill., *P.* cfr. *rugatus* Phill., *Marginifera* cfr. *schartymiensis* Yan., *Chonetes* cf. *hardrensis* Phill., *C.* cf. *variolaris* Keys., *Camarophoria*, typa *isorhyncha* McCoy, *Spiriferella? tschernyschewiana* Freder., *S.? kulindæ* Freder. and *Reticularia gasimurensis* Freder. These deposits mark approximately the northern border of the Mongolian geosyncline, the southern border of which is shown by the location of Sair Usu. (See map, pl. I).

Palæogeography of China in Dinantian Time.

(See Map Plate I.)

If we now attempt to reconstruct the palæogeography of China in Viséen time, we recognize by comparison of the various sections that the deposits were chiefly restricted to a series of geosynclines, with the exception of south-western China, where the region in and about Yunnan province represented apparently a more extensive basin. This, however, was probably closed on the south, extending part-way into Indo-China, but it opened on the west through the

Himalayan geosyncline, and on the north was continued in the Nanshan geosyncline of Kansu, where the sections described above are located Northern China was entirely unaffected by the Viséen transgression, but this extended along the Tsingling geosyncline, in the region of the present Yangtze valley, east for some distance beyond the Nanking region where it apparently ended without communicating with the Pacific of that time. It is clear from the sections that the southern line of this geosyncline lay to the north-west of Hangchow, in Chekiang province, where the Viséen is entirely wanting (see Pl. VI, col. G). Again it is absent in the Chou-Tang section of Kuei-Chih-Hsien in Anhui (Loc. 712), about 125 miles west of the Hangchow region. Here the Loping horizon of Middle Permian lies directly upon the Wutung quartzite of Silurian age. The southern border is again seen to lie north of Loping in Kiangsi, where the Dinantian beds are likewise wanting. North-west of this, however, in the sections of northern Kiangsi and Hupeh, the Viséen is represented by the Chihsia limestone and these regions are therefore included within the geosyncline of this period (see columns B. C. and D., pl. VI). The line is drawn between Leipakou and Huang-tu-pu, Honan, the latter having furnished Viséen fossils according to Yabe and Hayasaka (*Spirifer bisulcatus, Athyris royssi, Rhynchonella pleurodon*), while this horizon seems to be wanting at Leipakou. It is probably because of the long and narrow character of this geosyncline, and the fact that it was closed on the north-eastern end, that the fauna of the Chihsia limestone is distinctive and that many forms found in the Viséen of the more westerly region are absent. Like the Red Sea of today, which has its peculiar fauna related to, though in many respects distinctive from that of the Indian Ocean, so the fauna of this Chihsia sea, as we may call the water-body which occupied the Tsingling geosyncline, differed from the more normal faunal type of the Viséen which occupied the Yunnan region and extended through

the Nanshan geosyncline to the more open waters of central Asia. These in turn extended into the Mongolian geosyncline where typical Viséen deposits occur at Sair-Usu (Lat. 40° 45′ N., Long. 107° 30′ E.) and Gasimursk (Lat. 51° 10′ N., Long. 117° 6′ E.)

The Taiyuan Series.

(Plate II.)

North China. So far as the evidence now available permits us to judge, the Taiyuan series, which is classed as the last of the Dinantian divisions of China, is chiefly restricted to north China, though beds of this series are present in Yunnan and perhaps in Kwei-chow. That the Taiyuan fauna is in part at least derived from the Viséen is shown by the presence in it of Viséen elements, though these may be more or less modified. Most prominent among these is *Spirifer bisulcatus*, which may be regarded as the most typical member of this fauna. *Productus taiyuanfuensis* is likewise a modification of an earlier Dinantian type. Some elements may have wandered in from the European region at the end of Viséen time but the bulk of the fauna appears to be endemic.

So far no evidence of the occurrence of the Taiyuan fauna in south and central China has been found, and these basins appear to have been separated from the Taiyuan basin of north China by a broad and effective land barrier, the ancient Tsingling land of central China. During the flooding of the south Chinese region and the Mongolian geosyncline in Viséen time, north China was dry land and subject to erosion, and it is quite possible that the Ordovician limestone of north China contributed largely to the mass of lime-sand and lime-muds from which these Viséen strata are made. At the end of Viséen time, the waters withdrew from much of south China and apparently also from the Mongolian geosyncline, but readvanced

through the Nanshan geosyncline over north China, forming the Taiyuan basin in which the residual Viséen elements reappeared in modified forms.

The outline of the Taiyuan basin can be determined with a fair degree of approximation from the sections now available. The eastern border apparently lay only a short distance to the east of the present coast line of Chihli and there is no evidence that connection with the Pacific existed. In eastern Chihli (Kaiping basin) the Taiyuan series is chiefly represented by continental strata, the marine members being restricted to thin limestone beds, one of which, the Tangshan limestone, is the most prominent. Altogether, the thickness of the marine members comprised probably less than one meter.

The recent studies of Messrs. Chao and Tien of the Survey, in southern Chihli and Shantung have given us new data for the determination of the southern shore line of the Taiyuan basin. In Shia-Kou-Chuan, Chang-Ch'iu-Hsien, Shantung, about 150 miles south of the Kaiping basin, the Taiyuan series has a thickness of 240 meters or more, and carries five marine beds, these totaling 32.50 meters in thickness. This evidently indicates a region nearer to the center of the Taiyuan basin, where the marine waters lingered longest or returned most frequently. Fifty miles further to the south, in Lai-Wu-Hsien, Shantung, only one marine horizon with *Marginifera linchengensis* Chao, *Spirifer bisulcatus*, *Lophophyllum acanthiseptum* and *Productus taiyuanfuensis* occurs. In the Poshan coal field, half way between these two localities, but about 25 miles further east, the Taiyuan series contains two marine beds, a lower 4 meters in thickness and 12 to 50 meters from the base, and an upper 1.50 meter thick and 50 to 85 meters above the base. Thus we may draw the eastern boundary of the Taiyuan basin in Shantung some miles east of the Poshan region, and the southern boundary a similar distance south of Laiwu.

145 miles west of Laiwu, in the Tsechow and Liuhokou coal fields, of southern Chihli and northern Honan, the Taiyuan is again met with in pronounced marine development. Here five marine beds are recognized, aggregating nearly 17 meters in thickness, the Taiyuan series itself being only about 100 meters thick, or less than half its thickness shown in the Changchiu section. The following brief summary of this section has been contributed by Mr. Chao:

The Taiyuan series rests disconformably upon the Ordovician limestone and begins with shales and sandstones carrying three coal beds in the upper portion, the total having a thickness of 25.9 meters. This is succeeded by the TACHING LIMESTONE 10.37 meters in thickness, with some shales in the upper part. From these the following fossils have been obtained: *Productus taiyuanfuensis* Gr., *P. aculeatus* var. *echidniformis* Gr., *P. rectangulatus* Chao, *Marginifera linchengensis* Chao, *Enteletes lamarcki* Fischer, *Lophophyllum acanthiseptum* Gr., *Rhipidomella michelinioides* Gr. & Chao, *Hustedia bella* Gr., *Spirifer pankouensis* Gr., *S. bisulcatus* mut. ψ, etc. This horizon appears to represent the Pankou limestone of Shansi. Overlying it are 15.3 meters of unfossiliferous shales and sandstones with a coal bed at the top and then follows the second limestone about 1.5 meters in thickness. This is the HSIAOCHING LIMESTONE, which is especially rich in two brachiopods, *Productus taiyuanfuensis* Gr. and *Orthothetes taiyuanfuensis* Gr. This horizon probably represents the Miaokou limestone of Shansi. It is succeeded by 8.6 meters of shales, again with a coal bed at the top, above which follows the third limestone, 2 0 meters in thickness. This has been called the FUCHING LIMESTONE and abounds in *Fenestella*. It is succeeded by 7 meters of sandstones with a coal seam near the top and on this rests the fourth limestone, 2.5 meters in thickness. This is the SHANCHING LIMESTONE and it contains the following species in abundance: *Lophophyllum acanthiseptum* Gr., *Productus taiyuanfuensis* Gr., *Marginifera lopingensis* var. Succeeding

it are 18.6 meters of shales, terminated again by a coal bed and followed by the fifth limestone of the region 0.85 meters in thickness. This is the YEHCHING LIMESTONE, the highest marine bed of the region, characterized by *Spirifer bisulcatus*. It is followed by more unfossiliferous shales. *Fusulina* is abundant in all the limestones. It will be observed that all the continental sediments of this series terminate in one or more coal beds and these are immediately followed by the marine limestones. Thus the marine invasion always followed the development of low swampy areas, and was succeeded by a period of vigorous continental sedimentation.

Sixty miles further north, at Lincheng in western Chihli, another good section of this formation is known. Here, however, only 3 limestones are shown with an aggregate thickness of 8.7 meters, but the section is undoubtedly incomplete, probably through pre-Permian erosion. The succession, in this section, is as follows according to Mr. Y. T. Chao, (in descending order):

TRIASSIC? red sandstones, more than.....500 meters

UPPER PERMIAN, about.....450 meters

Red, sandy shales and white sandstones in upper part; variegated shales and thin beds of sandstone in lower part.

LOWER PERMIAN, about.....110 meters

Shansi series, sandstones and shales with a thick bed (30 meters) of gray sandstone at the base. No marine beds.

Disconformity

TAIYUAN SERIES, about.....155 meters

7. Shales..... ....10.0 meters (?)
6. *Peiching limestone*.....1.2 meters
5. Yellow shales.....9.7 meters

4. *Houkout limestone*..... 2.9 meters
3. Sandy shales..... .....47.0 meters
2. *Chitsun limestone*..... 4.6 meters
1. Sandstones and shales.....80.9 meters

Disconformity

ORDOVICIAN LIMESTONE.

The CHITSUN LIMESTONE is the thickest of the series, and is of massive character and gray color. Besides crinoidal stems it has only furnished the following species: *Spirifer bisulcatus* Sow. (mut.), *S. pankouensis* Gr., *Marginifera linchengensis* Chao, *Enteletes* sp., *Dielasma* sp.

The HOUKOUT (HOUKOUTSUN) LIMESTONE is the most fossiliferous bed of the region, the abundance of crinoids in it having led to its being regarded by the farmers as a source of "stone coins". According to Messrs. Chao and Tien it is divisible into three parts. An upper violet ferruginous limestone, a yellow impure crinoidal limestone with *Pinnatophyllum wangi* and a lower soft calcareous shale abounding in *Deltopecten giganteus*. More than 50 species of fossils have already been identified including 9 species of crinoids belonging to the genera *Sinocrinus* (Tien), *Ceriocrinus* and *Eupachycrinus*. The most abundant corals are *Pinnatophyllum wangi* Chao, and *Lophocarinophyllum acanthiseptum* Gr. The commoner brachiopods include *Spirifer bisulcatus* Sow. (mut.), *S. derjawini* Yan., *Productus taiyuanfuensis* Gr., *P. echidniformis* Gr., *P. semireticulatus* Mart., *P. costatus* Sow. (var.), *P. punctatus* Mart., *Marginifera linchengensis* Chao, *Rhipidomella michelinioides* Gr. & Chao, *Orthothetes crenistria* Phill. (var.), *Spiriferina willisi* Gr., *Chonetes* cf. *nyströmi* Gr. Pelecypods are numerous including the large pectenoids *Deltopecten giganteus* Chao, and *D. multistriata* Chao, besides *Acanthopecten shansiensis* Gr. A number of other species of pelecypods and of gastropods and cephalopods also occur in this stratum, many of them being new.

The PEICHING LIMESTONE contains essentially the same fauna, though the number of species appears to be smaller. With these, however, occurs the new genus of foraminiferan named by J. S. Lee *Grabauina* (genotype *G. disca* Lee) a form intermediate between *Fusulinella* and *Fusulina* (Lee 36).

The Shansi series, as well as the higher Permian in this region, are wholly non-marine, indicating that the Shansi transgression covered a much smaller area than did that of the Taiyuan epoch.

About 100 miles west of Lincheng lies Taiyuanfu in the vicinity of which the most complete series of sections has been made. These sections have already been described in the previous chapter (see *ante* p. 254, Fig. 178, sections III, IV and V). Eight distinct limestones are here recognized in the various sections, these having an aggregate thickness of 39.65 meters. They comprise the following in descending order:*

8.	Kuanti limestone.....	3.95 meters
7.	Shihchiwa limestone.....	3.0 ,,
6.	Hsiehtao limestone.....	2 5 ,,
5.	Maoerh limestone.....	8 2 ,,
4.	Miaokou limestone.....	12.2 ,,
3.	Pankou limestone.....	5.7 ,,
2.	Nanyao limestone.....	2.8 ,,
1.	Chientaokou limestone....	1.3 ,,
	Total	39.65 meters

This is the thickest and most complete section of the Taiyuan series now known, but it must be borne in mind that, as in the other sections so far described, these limestone beds are interbedded with

* The revised spelling of these names is here given. See list at the end of this chapter.

sands and clays, many of them coal-bearing. Thus it is evident that even in this region the Taiyuan basin was flooded at intervals by marine waters from an outside source, these floodings being interrupted by periods of continental sedimentation.

About 100 miles north-west of Taiyuanfu we meet with another good section of this formation near Paotechou in west Shansi. Here, however, the Taiyuan formation is only about 42 meters thick and contains only two marine beds, a lower (Changchiakou limestone) 1.2 meters thick, and about 20 meters above this, a higher (Palou limestone), 8 meters thick. The Taiyuan series is separated from the Shansi series by a coal bed 20 meters in thickness. These beds, as before noted, correspond to the lower members of the series in the Taiyuanfu region of central Shansi, and it appears that we are here approaching the northern rim of the Taiyuan basin.

One hundred and eighty miles south of Taiyuanfu, and south of the Yellow River, is the Kunghsien section of north Honan. Here Nyström and Erickson have collected some corals apparently from rocks of the Taiyuan series but the details of the occurrence have not been determined. The southern shore of the Taiyuan basin may, however, be placed south of this locality.

Further west in the Hsin-An (Hsinan or Sin-An) region of northern Honan, the section shown in Fig. 283 on page 394, was made by Nyström. The Taiyuan series here rests disconformably upon the Ordovician limestone and includes a thin *Fusulina* limestone. From dark shales in the lower part of the section near Kuang-K'ou on the Yellow River the following characteristic Taiyuan species have been obtained (Locality 303): *Chonetes nyströmi* Gr., *C. pankouensis* Gr., *Productus taiyuanfuensis* Gr., *Orthothetes* cf. *taiyuanfuensis* Gr , *Euphemus* sp., Crinoidal stems. This region is not far from the southern border of the marine Taiyuan basin.

Much new information regarding the Taiyuan, as well as the Viséen and Shansi series, has recently been obtained in Kansu during more than a year of exploration by Mr. Phillip Yuan of the Survey. The localities studied by him lie between 400 and 550 miles west of Taiyuanfu, extending from the vicinity of Wu Wai (Liang-Chow-Fu) to near the Bardoun river, and including the localities previously studied by Loczy and Hsieh. The faunas have not yet been studied in detail but preliminary examination shows much new and interesting material.* In one of the western-most sections at Mo-kou (Hei-Shi-Shia), 70 li (28 miles) south of Fu-I-Hsien (approximately Lat. 100° E., Long. 39° 25′ N.) the following section was made by Mr. Yuan in descending order:

SUPER-FORMATION. Permian coal series

Disconformity

TAIYUAN SERIES

d. Bellerophon beds.....6.0 meters
richly fossiliferous shales with abundant gastropods.

c. Unfossiliferous shales.....6.0 meters

b. Marine limestone with *Spirifer bisulcatus* and a large Nautilus species.....0.5 meters

a. Conglomerate and sandstones..... 4.0 meters

Unconformity

SUB-FORMATION. Nanshan sandstones.

The Taiyuan series is here 16.5 meters thick and rests directly on the Nanshan series of pre-Cambrian time, thus overlapping the Viséen beds. The Bellerophon shale (bed d) is especially characterized by gastropods, among which *Bellerophon* sp. nov. and *Loxonema szechenyii* Loczy (Fig. 155, p. 237) are the dominant types.

* The details of the sections and their location have been furnished by Mr. Yuan.

At Yao-Kou, about 18 miles (45 li) west of Mo-Kou, the Taiyuan series is 20.5 meters thick resting unconformably on igneous beds and being succeeded disconformably by Permian beds. The marine facies of the Taiyuan however, is represented only by two thin limestones totalling 3.5 meters in thickness. These are embedded in continental sands and shales and indicate periodic invasions of this region by the sea. The lower of these limestones, 2 meters thick, contains corals and brachiopods (*Spirifer*, etc.); the upper carries *Fusulina*.

About 100 miles (250 li) east of Mo-Kou at Hsin-Ho, the continental series is thicker, though not fully exposed, but there too only 2 marine beds, totalling 2.45 meters in thickness, are interbedded in the continental series. Both of them carry *Fusulina*, and this and the preceding section therefore mark the coastal region of the Taiyuan waters, only temporarily flooded by the sea.

A more extensive marine series is shown at Li-Chia-Chuan, 20 miles (50 li) south of the preceding. Here the Taiyuan series also rests unconformably upon the Nanshan. It has a thickness of 45 meters and is disconformably succeeded by beds of Permian age. Here the series begins with 10.8 meters of continental beds followed by a marine limestone 1.5 meters thick. This is succeeded by a non-marine bed 0.8 meters thick, above which lies a second marine series of shales and limestones 5.8 meters in thickness. Then follow 26 meters of continental beds, which however carry a *Fusulina* limestone 2 meters thick in their upper part.

Still more complete is the section at Hung-Shan-Yao, 26 miles (65 li) further to the south-east. Here a thickness of 76.4 meters of the Taiyuan series is exposed but the base of the section is covered. The marine series has an aggregate thickness of 35.2 meters, that is, nearly one-half the exposed section consists of marine

beds, the continental beds being chiefly confined to the upper part of the series. From 46 to 50 meters below the Permian is a limestone bed rich in fossils, among which the following are common (Locality 539): *Orbiculoidea* sp. nov., *Rhipidomella michelinioides* Gr. and Chao, *Reticularia rotundata* Gr., *Chonetes pseudovariolata* (Nikitin) Loczy, *Productus taiyuanfuensis* Gr., *Marginifera loczyi* Chao, *M. longispinus* (Loczy), *Spirifer pankouensis* Gr., *S. bisulcatus* Sow. mut., *Euomphalus* sp., *Hustedia bella* Gr.

In the Cho-Niu-Kou section, 100 miles (250 li) S. E. of Hung-Shan-Yao and 28 miles (70 li) W. by S. from Wu-Wai (Liang Chow-Fu) the Taiyuan is 15.5 meters thick and is separated from the Viséen by 5 meters of plant-bearing non-marine sandstones. It is disconformably succeeded by beds of Lower Permian age.

South West China—Yunnan. The Taiyuan series is represented in the Yunnanfu region by the Eurlkai (Eulkai) group, which has been referred to above (p. 246) as carrying a fauna in which many species of Viséen characteristics are retained. This is the horizon from which *Spirifer bisulcatus* var. *weiningensis* Grabau was cited by Mansuy under the name of *S. mosquensis*. Coggin Brown (7, p. 100) refers to the deposits at Eurlkai, 25 miles southwest of Yunnanfu (Long. 102° 34′ E., Lat. 25° 41′ N.) as Middle Carboniferous, and Cowper-Reed (45, p. 218) lists the fossils as Upper Carboniferous. The beds consist of sandy yellow shales followed by limestone bands, the beds striking north 20° west and dipping at high angles towards the east. At the mine, Brown determined the succession to be in descending order:

d.	Dolomitic limestone	?
c.	Limestone with *Euomphalus*	10 ft
b.	Sandstone with coal seams	40 ft.
a.	Reddish limestone	—

From the limestone (c) the following fauna was obtained by Reed: FORAMINIFERA:* *Endothyra* cf. *bowmanni* Phill., *Fusulinella* sp., *Spirillina* sp.; ANTHOZOA: *Campophyllum vigilans* Reed (sp. nov.); BRACHIOPODA: *Productus* sp., *Streptorhynchus* aff. *pelargonatus* Schloth , *Athyris* (*Seminula*) cf. *subtilita* Hall, *A.* (*S*) *eulkaiensis* Mans?, *Spirifer* sp.; GASTROPODA: *Euomphalus* (*Schizostoma*) cf. *catillus* Mart., *Pleurotomaria* (*Mourlonia?*) *eulkaiensis* Reed (sp. nov.), *Bellerophon* (*Waagenella*) sp. According to Brown the dolomite limestone (d) carries *Chætetes subradians* Mans.

Four coal seams were reported by Lantenois in this series, but Brown only noted two, each about 4 feet thick and separated by a thin series of sandstones and shales.

The same series is also exposed 8 miles further to the northeast at Hsintsun on the Po-tu-ho, where the rocks are almost horizontal. It is again seen 10 miles north of Yunnanfu at Yen-tzu-shao (Long. 102° 42′ E., Lat. 25° 12′ N.), where the succession in descending order is:

c. White fossiliferous limestone
b. Sandstone and shale with thin coal seams
a. Sandy limestone

The white limestone has furnished, according to Brown, *Fusulinella* sp., *Spirillina* sp., *Endothyra?* sp., and according to Reed, *Dibunophyllum?* sp., *Spirifer* (*Martiniopsis*) *orientalis* Tschern. var., and *Porcellia?* sp.

Summarizing the information we have at present of the stratigraphy of the Yunnan-fu region, we find both Viséen and Taiyuan horizons represented, the gastropod limestone (Laotien and Choueitang) may represent a part of the Middle Carboniferous, but

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* According to Coggin-Brown.

above this follows disconformably the lower marine Permian, succeeded in turn by Red Beds.

Palæogeography of China in Taiyuan Time.

(Map Plate II.)

From the Cho-Niu-Kou section it is clearly seen that the Taiyuan series overlies the Viséen beds, but it is separated from them by beds of continental character. No section is as yet known in which the Viséen and the Taiyuan are entirely continuous unless this occurs in the south-west Chinese basin where, as we have seen, a part of the Taiyuan may be represented by the Weining and other limestones. These Yunnan strata are, however, as yet too little known to permit us to form accurate conclusions.

From the sections so far obtained it is evident that the Taiyuan basin was not continuously occupied by marine waters but was repeatedly flooded from some outside source, and with each flooding the returning fauna was to a greater or less extent modified. Thus we must postulate the existence of some basin in which this modification was going on and from which the progressive floodings proceeded. Where was this basin located? There are three possible answers to this question. The first is that it was located in Sinkiang and the region to the west of it in central Asia, and that the Taiyuan basin was flooded through the Nanshan geosyncline. However, the Kansu sections which lie in the very heart of this geosyncline so far show only an incomplete representation of the Taiyuan series and many of the types which are known in the interior have not yet been found in the Kansu section. Thus with our present knowledge we are hardly justified in considering the fauna of the Taiyuan basin to have entered from the north-west.

The second point of connection might be considered as having been on the east. As we have seen, the Kaiping and Changchiu

sections are about 150 miles apart and nothing is at present known from the region between. It is not impossible that an opening existed on the east somewhere along the line of the present Yellow Sea to the Pacific of the period, though certainly there is no evidence whatever for the existence of such a connection. The question can only be settled definitely by the discovery of intermediate sections between those now known. If these show an increasing marine series the probabilities of such a connection are strengthened, whereas if the number of marine beds is reduced we must postulate that there was a continuous shore line on the east. In that case only the third alternative remains and that is that the Taiyuan fauna developed in the Szechuan-Yunnan basin of south-western China and that the Taiyuan basin was repeatedly flooded from this source around the western end of the Tsingling old land. This seems at present the most plausible answer to our question, for it is in this region that we have a great unexplored inland area, which we know was covered by marine waters during the Viséen period and which may have remained more or less an isolated basin, the waters of which repeatedly flooded the Taiyuan basin on the north-east and passed through the Nanshan geosyncline towards the central Asiatic region to which they supplied many of the modified forms which there became the dominant mid-Carboniferous types. The solution of this problem, therefore, awaits the study of the great marine limestones of south-western China.

Extra-Chinese Territory.

Boehm (3) has reported the existence of *Posidonomya becheri* from Nohewi?, island of Sumba, in the Dutch East Indies, about latitude 9° 40′ S., longitude 119° 30′ E. This is probably to be regarded as an extension of the *Posidonomya becheri* beds of the Malay peninsula described on page 293 *et seq.* and indicates the extent of the marine areas in the Indian Ocean region in Taiyuan time.

Permian System.

Central and South-East China.

So far as the evidence now at hand permits us to judge, the Permian basin of the eastern part of central and south China was entirely distinct from that of north China, the two apparently having distinct inter-oceanic communications, at least in the earlier part of the Permian period. South-eastern China was characterized by the existence of a geosyncline, which extended north-eastward through Kiangsi and the border region of Chekiang, Anhui and Kiangsu. Here we recognize the transgression of the sea in Permian time and its gradual spread, as shown by the overlap of the successive formations. The geosyncline opened to the Pacific on the east in the region of the Yangtze mouth, and on the south-west joined the waters which covered Kweichow, Szechuan and eastern Yunnan.

We will first consider that part of the geosyncline which extended from the Kiangsi-Hunan border north-east to the Yangtze mouth. What are believed to be the oldest marine beds in this region, marking the center of the geosyncline, are those carrying the Loping or *Lyttonia richthofeni* fauna. The famous Loping basin lies in north-east Kiangsi, east of the Poyang lake (about Lat 28° 45′ N., Long. 116° 50′ E. See Map Pl. IV). A section of this has been given on page 362. The basal beds of this basin consist of shales of unknown thickness, which rest unconformably upon the older pre-Palæozoic rocks. It is not known whether these shales contain fossils or not. They may represent a lower horizon in the Permian or they may even be of Lower Carboniferous (Dinantian) or earlier age. They are succeeded with apparent concordance by the main coal bed, above which lie the shales and limestones which carry the Loping fauna.

More than 200 miles north-east of Loping we meet with this fauna again in Tung-Ting-Hsishan in southern Kiangsu (Locality 601

about Lat. 31° 15′ N., Long. 120° E.). Here again the base of the series is not shown nor is the underlying rock known, the outcrops representing later beds of dark limestones. From these the following species have been obtained *Lyttonia richthofeni* Kayser, *Reticularia waageni* Loczy, *R. indica* Waag , *Productus* sp., *P. kiangsiensis* Kayser *Martinia triquetra* Gemm. var. *lopingensis* (*M. elliptica* Kayser), *Marginifera lopingensis* Kayser, *Derbya grandis* Waag. *Orthothetes* cf. *eusarcus* Abich, *Pseudomonotis?* sp., *Phillipsia obtusicauda* Kays.

The Lyttonia fauna is also found at Chou-Tang, Kuei-Chih-Hsien, Anhui (Loc's 709-712). Here the following section was made by Messrs. Yih and Li, in descending order:

PERMIAN

Changsing and younger horizons

3. Dark carbonaceous limestone and shale with fossils near the base (711).....150 m.

Loping horizon

2c. Yellowish gray calcareous shales with the typical Loping fauna, including *Lyttonia richthofeni*, *Marginifera lopingensis*, *Productus* cf. *gratiosus*, *P. kiangsuensis* Chao, etc. (Loc. 712) ..... 1 m.

2b. Dark massive or thick-bedded cherty limestone with a few fossils of the Loping type (710) ..... 30 m.

2a. Dark carbonaceous shales and limestones with fossils of the Loping horizon .... 10 m.

Disconformity

SILURIAN

1. Wutung quartzite and shales.

The interest of this section lies in the fact that the Loping horizon here follows directly upon the Silurian quartzite, overlapping

the Chihsia limestone. Together with the type locality at Loping it gives us also two points in which we find the Loping horizon resting directly upon the older rocks and thereby representing the extent of the invasion of the Loping waters.

As above noted, the Loping fauna is especially characterized by *Lyttonia richthofeni*, and as this form is also found in Vladivostok and in Japan, connection with the Pacific was evidently established (see the map, page 325). The south-western extension of this fauna can not at present be traced, but it was certainly to the north of Leipakou in Hunan, probably in the Changsha district, whence it extended westward to Kweichow (Tung-Tze-Hsien) and Szechuan (Ki-Kiang-Hsien), from which localities this fauna has been reported. We had previously identified the Loping fauna from the Iron Ore region of Tao-Chung, in eastern Anhui but this requires further study and verification. On the north, the Loping fauna seems to be included in the lower part of the limestone series which forms the great cliffs of the Yangtze and which has been classed as a whole as the Wushan limestone by Willis and Blackwelder. The lower part of this limestone, as already noted, is now known to be of Dinantian age, but beds with *Lyttonia richthofeni*, *Oldhamina* sp., *Productus abichi* Waag., *Reticularia waageni* Loczy and *Productus sumatrensis* var. *palliata* Kays., occur about 500 meters above the horizon of the Dinantian fauna. This is probably the Changsing or *Oldhamina* fauna, which is believed to overlie the *Lyttonia* fauna in the eastern region. However, the association of *Lyttonia richthofeni* with *Oldhamina* in these beds on the Yangtze indicates that the horizon of the Lyttonia fauna is also included in these limestones and we may at present consider that the 500 meters or more of limestone, which overlie the Dinantian beds of this region, include both the *Lyttonia* and the *Oldhamina* faunas. These deposits evidently belong to the eastern extension of the Tsingling geosyncline which joined the Loping

geosyncline, as we may provisionally call it, approximately at right angles in the region north of Nanchang in Kiangsi. The waters of this Tsingling geosyncline were apparently confined to the Yangtze region in Hupeh. Certainly there is no known indication of these faunas in Honan, where on the other hand we meet with faunas of the northern type which are as yet unknown in the Yangtze region. It is quite probable that the geosyncline at this time included the Choutien region of northern Szechuan, a section of which is given on page 370, with description on page 367, though at present the fossil evidence for the existence of the *Lyttonia* fauna in that region is lacking.

What appears to be the next higher horizon is shown in the limestones of the Changsing coal district of northern Chekiang (Locality 900) where the following species have been obtained:* *Oldhamina decipiens*, *Reticularia waageni* Loczy, *Productus gratiosus* Waag., *P. sumatrensis* Roemer var. *palliata* Kays , *P. abichi* Waag., *P. mongolicus* Dien., *P.* sp., *Marginifera lopingensis* Kays., *Martinia warthi* Waag. var. *sulcatus* Chao, *Orthothetes* cf. *eusarcus* Abich, *Enteletes* sp., *Tainoceras* sp., *Tachylasma aster* Gr., *Reticularia inæquilateralis* Gemm. var. *lopingensis* Gr. It is possible that in this region the beds with the Loping fauna underlie those with the *Oldhamina* fauna but they have not been found in immediate association. Thirty or forty miles to the south, however, in the Hangchow district of Chekiang, the *Lyttonia*, as well as the *Oldhamina* beds, are entirely wanting in their marine facies though they may be in part represented by continental coal-bearing beds. The first marine bed here, however, belongs to the Hsiaochiang horizon, which according to our present understanding, overlies the beds with *Oldhamina*. There is thus indicated an overlap on the south-eastern margin of the

* Identification by Y. T. Chao.

geosyncline. In like manner, if we turn to the north-west border of the geosyncline, we find in the Hsuanchin coal region of eastern Anhui (Loc. 722-730) about fifty miles due west of the Changsing region, that the *Lyttonia*, as well as the *Oldhamina* beds are again

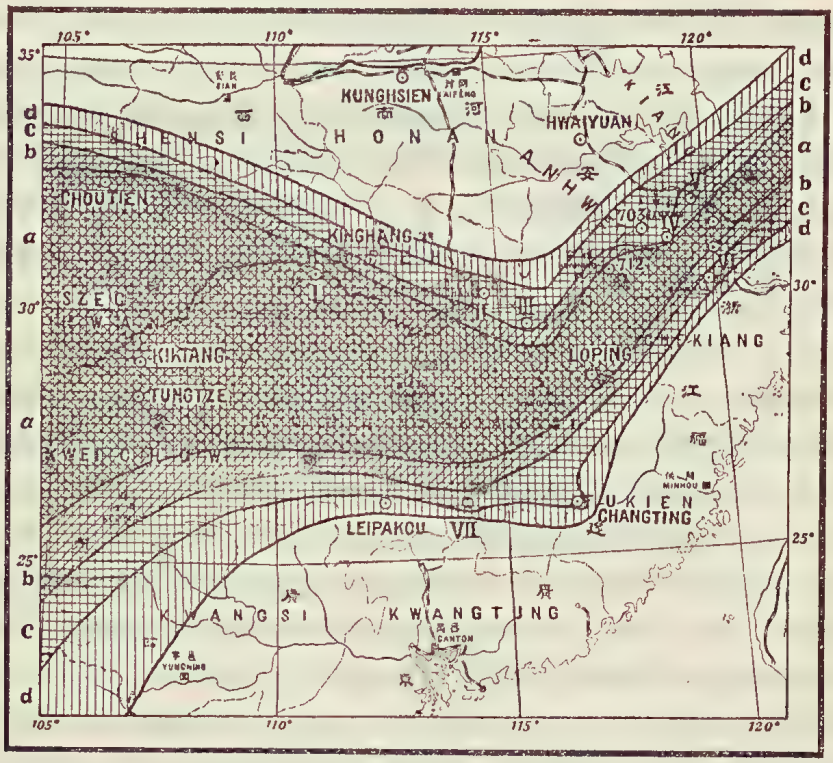

Fig. 299. Map of South China showing the extent of the sea during the successive epochs of the Middle and Upper Permian, and the progressive overlaps of the younger over the older formations. The stages are indicated in the margins as follows: *a*, *a*, Loping epoch (*Lyttonia* Fauna); *b*, *b*, Changsing epoch (*Oldhamina* Fauna); *c*, *c*, Hsiaochiang epoch (*Orthothetes tingi* Fauna); *d*, *d*, Paoan and Tayeh epochs (*Gastrioceras* and later Faunas). The Roman numerals I–VII in the map indicate the locations of the sections in Plate V. Other localities named, except 703-Tao-Chung, and 712-Choutang.

overlapped, the first marine bed also being formed here by strata of the age of the Hsiaochiang formation. Thus the width of the geosyncline is, in this region, fairly well indicated (Fig. 299). The distance between the Hangchow and the east Anhui regions, in both of which the Loping and Oldhamina faunas are wanting, is approximate-

ly sixty miles, the direction being north-west and south-east, or essentially at right angles to the direction of the old geosyncline. Bearing in mind that the distance has been fore-shortened by the subsequent folding of the strata of the geosyncline, we may perhaps regard the width of the original geosyncline in this region as something less than the width of the northern end of the Red Sea, below the Sinai peninsula. South-westward, however, this expanded to more than twice that width.

The Loping and *Oldhamina* horizons are succeeded by the Hsiaochiang horizon, which is typically developed in the Chian district of south-western Kiangsi (about Lat. 26° 20′ N., Long. 114° 15′ E.). The succession in this region has already been given (p. 361), where it will be seen that the Hsiaochiang limestone, formerly called Hsiaochiang-pien limestone, forty meters thick, rests upon the Aochêng coal series, which may represent the horizon of the Loping coal, although the palæontological evidence for that is at present lacking. The Hsiaochiang limestone contains an important fauna in which species of *Orthothetes* predominate with *O. tingi* (Fig. 247, p. 359) as the leading type, while *Orthotichia morganiana* Derby var. *sinensis* Gr. (Fig. 300) is an equally characteristic and typical form. It should be noted that this species was originally described from the upper coal measure beds of South America (Brazil and Bolivia), where it appears to be a characteristic form. Again it has been identified by Tschernyschew in his Upper Carboniferous formation (Schwagerina beds) of the Ural region, in Russia, and of Darwas. This form is entirely unknown in the Indian

Fig. 300.
Orthotichia morganiana Derby, var. *sinensis* Grabau. Type from Feilaifông Limestone, Chekiang (Cat. 725), nat. size.

Permian, and it is quite probable that it entered the south Chinese region from the Pacific, especially as this species is also found in the north-eastern portion of this south Chinese geosyncline. The path by which it reached the Russian region is not so readily determined. It may have reached that distant country by way of the Mongolian geosyncline, though at present the species is not known from Mongolia.

Because of the importance of the fauna of the Hsiaochiang formation, a more complete list of the species so far identified, is here inserted, the following list representing the known species of the fauna of the Hsiaochiang Formation:

BRYOZOA: *Synocladia* sp.; BRACHIOPODA: *Productus semireticulatus* d'Orb., *P. gratiosus* Waag., *P. rhynchonelloides* Chao, *P. chianensis* Chao, *P. alternopustulosus* Chao, *P. cora* d'Orb., *Schizophoria chianensis* Gr., *Orthotichia morganiana* Derby var. *sinensis* Gr., *Orthothetes tingi* Gr., *O. anderssoni* Gr., *O. anderssoni* mut. *heterostriata* Gr., *O. carinostriata* Gr., *O. carinostriata* mut. *sinuosa* Gr., *Spiriferina chuchuani* Gr., *Reticularia lineata* Mart., *Ambocœlia* cf. *planoconvexa* Shum.

The Hsiaochiang formation is immediately succeeded by the Fêngtien series, which in its upper part, carries the highest marine Permian fauna at present known from south-eastern China, and which, as will be shown presently, has a wide distribution in this region. Hence it is evident that the Hsiaochiang formation indicates an overlap of later Permian over the *Oldhamina* and *Lyttonia* horizons. As above noted, the non-marine Aochêng coal series, which underlies the Hsiaochiang limestone, may represent the Loping horizon. Here again we have a point in the eastern border of the Loping geosyncline, this serving to determine the approximate outline of this water-way.

There is, however, another locality 100 miles or more to the east of the Chian region, which must be taken into account in this

connection. This is at Tingchowfu, Changting in western Fukien, a region which has been studied by Mr. S.W. Wang of the Survey. Here he discovered a dark shale layer litterally crowded with specimens of *Productus cora* var. *fukienensis* Chao with more rarely *P.* cf. *subcostata* Waagen, *Marginifera ornata* Waagen and *M. frechi* Chao. It is one of the few marine horizons in the Permian of this eastern region and represents apparently the lowest one. Because of its limited development it is probably to be regarded as formed in a local embayment or estuary of this region for, as will be shown presently, the great mass of beds in this locality is of continental origin with fresh-water mollusks, and with plant remains. It is quite possible that this represents the period of the Hsiaochiang expansion, though it may be younger.

About 370 miles due north-east of the Chian locality, in the hills around Hsihu, western Hangchow in Chekiang province, essentially the same relationship is shown, the first marine Permian bed being the equivalent of the Hsiaochiang of Kiangsi. This then marks two points along the border of the Loping geosyncline, where the late Permian beds overlap the *Oldhamina* and Loping horizons. The section (Plate V, Section VI) begins with the Laoho shales and sandstones 250 to 400 meters in thickness, which rest unconformably upon the folded Ordovician strata (Kinshan beds), the upper members of which have yielded an *Orthoceras* comparable to, and perhaps identical with, *O. chinense* of the Upper Ordovician. The age of the Laoho series is undetermined, consisting according to Mr. T. O. Chu, entirely of unfossiliferous clastic beds. At the base there are conglomerates which are followed by white sandstones, which in turn are overlain by brown micaceous sandstones, part of which becomes a quartzite. Nearer the middle are violet and green sandstones and the upper part consists of hard and compact sandstones, showing the evidence of recrystallization. This may be provisionally correlated

with the Aochêng series of south-western Kiangsi and the Oldhamina and Loping horizons of the central part of the geosyncline, of which these beds appear to represent the continental equivalent. The Laoho sandstones are followed with apparent conformity by the FEILAIFÔNG formation, which consists of thick-bedded light gray limestones containing occasionally flint nodules and lenses, and enclosing, besides numerous Foraminifera (*Schwagerina*), several characteristic brachiopods, *i.e.*, *Orthothetes tingi* Gr., *Orthotichia morganiana* var. *sinensis* Gr., *Productus* sp., and *Griffithides* cf. *obtusicauda*. This is evidently the horizon of the Hsiaochiang formation of Kiangsi.

The same formation is again met with on the opposite side of the geosyncline in south-eastern Anhui (Plate V, Section IV), where the Yehshan limestone, the equivalent of the Chihsia limestone of Upper Dinantian age, is disconformably succeeded by the KOOFÊNG limestone (Locality 723). It is characterized by *Griffithides* cf. *obtusicauda* identical with the form found in the Feilaifông limestone of east Chekiang and like that, represents the Hsiaochiang horizon. This is succeeded by the HSUANCHIN coal series, which in the basal part contains *Chonetes* sp., *Aviculopecten* sp., and higher up *Productus sinensis* Frech, a form also known from the Wushan limestone of the Yangtze and the Peishan limestone of north-western Kiangsi, and like the latter, representing the Upper Permian horizon. Other fossils found in the middle Hsuanchin coal series are *Marginifera* cf. *spinocostatus* and *Productus gratiosus*.

The Hsiaochiang horizon is again found in the upper part of the Tsoshan limestone in the Su-Sung district of south-western Anhui and the Jui-chang and Hsiu-shui districts of north-western Kiangsi. Here we again find *Productus chianensis* Chao, a characteristic form of the Hsiaochiang formation, together with some other species. Here, as in other sections, the limestone overlies disconformably the Chihsia limestone of Dinantian age together with which it is here classed as

the Tsoshan limestone. The locality lies about 70 miles north-west of Loping and therefore marks the north-western border of the Loping geosyncline. About the same distance further to the north-west, in the Wuchang region of south-eastern Hupeh, identical conditions are met with. Here the Yangsing limestone 400 meters or more in thickness, the approximate equivalent of the Tsoshan limestone,

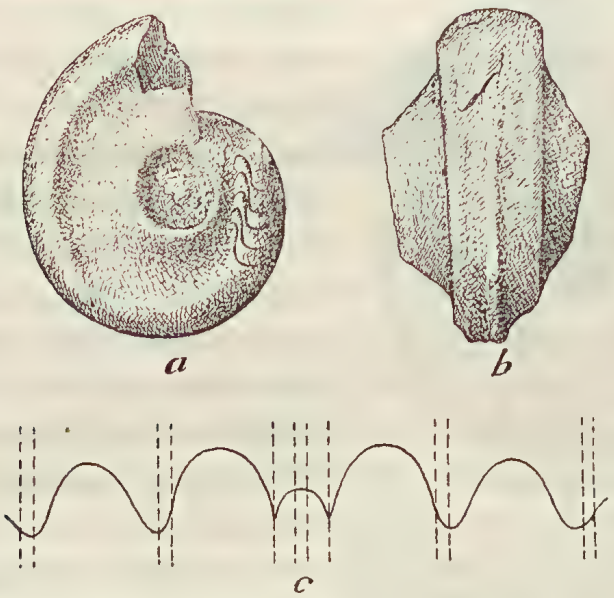

Fig. 301. *Glyphioceras* (*Anderssonoceras*) *anfuense* Gr. Type from Fêngtien shale, S. W. Kiangsi. *a*, Side view; *b*, ventral view of another shell; *c*, suture. *a*, *b*, enlarged × 1½; *c*, much enlarged.

carries the Chihsia Dinantian fauna in the lower part and the Hsiaochiang fauna in the upper, these two parts being separated by a disconformity which covers the whole of the Middle and Upper Carboniferous and the lower half of the Permian (Plate V, Section II). This and the preceding section form essentially equivalent localities along the north-eastern border of the Tsingling geosyncline, which here joins the Loping geosyncline nearly at right angles as above noted. The Hsiaochiang horizon is again represented in the lower part of the Upper Wushan limestone of the Yangtze gorges,

and by certain beds in the Tapashan section of the Choutien district in north-eastern Szechuan, though at present we cannot make precise correlation.

Throughout the south-eastern region, the Hsiaochiang limestone is succeeded by a coal horizon which has received various names in the different sections and this is followed by the PAOAN shale, which is the horizon of *Gastrioceras zitteli*. In the Chian region of south-west Kiangsi (Plate V, Section VII), these two horizons are represented by the Fêngtien series 200 meters thick, with coal and fossiliferous marine shales characterized by *Enteletes magniventra* Gr., and black shales with *Glyphicoceras* (*Andersonoceras*) *anfuense* Gr. (Fig. 301) and *Gastrioceras* (*Girtyites*) *liui* Gr. (Fig. 302), both of these goniatites being widely associated with *Gastrioceras* (*Girtyites*) *zitteli* (Fig. 261 p. 371) in the Paoan shale horizon of the Yangtze valley.

Fig. 302.

Gastrioceras (*Girtyites*) *liui* Grabau. Compressed shell preserved in iron pyrite and showing form, involution, and growth-lines. The spirally ornamented outer portion is added from another individual × 1. Paoan shale, S. Anhui; (type).

The form described as *Gastrioceras zitteli* Gemm. belongs to the genus *Girtyites* of Wedekind (62). This genus was separated from *Gastrioceras* because of the spiral sculpture of at least a part of the shell. *G. zitteli* was first found in China by von Richthofen in the Tapashan section in the Choutien district of north-east Szechuan (bed e, Fig. 259, page 370) and described by Frech (Fig. 261). It was next recognized by Hayasaka in the Taochung mining district of Anhui (Loc. 703) and obtained by Hsieh from the Paoan shales of south-eastern Hupeh. In this region it is associated with *Gastrioceras*

(*Girtyites*) *liui* Gr. (Fig. 302), both shells being pressed flat upon the brown paper-shales, and only showing the form and sculpture of the shells but not the suture (see Section II, Plate V). Messrs. Yih and Li obtained *G. liui* in the upper Hsuanchin coal series in beds representing the Paoan of Hupeh (Sect. IV, Plate V). In these beds it is associated with crushed shells of *Glyphioceras* (*Anderssonoceras*) *anfuense* Gr. (Fig. 301) and some other forms, but it is always flattened, and frequently preserved in pyritized condition.

Prior to this Mr. T. C. Wang obtained this shell in abundance in the black shale of the Fêngtien formation of the Chian district, south-west Kiangsi. Here it is associated with uncrushed shells of *Glyphioceras* (*Anderssonoceras*) *anfuense* Gr. (Fig. 301); both goniatites being so well preserved as to place their association beyond doubt. Either appears to be a good index fossil of this horizon and since *G. liui* is associated with *G. zitteli* in Hupeh, they, as well as this latter species, serve to indicate this very definite horizon in the Permian succession of the Yangtze Valley. When developed in shale facies it is known as the PAOAN SHALE or the horizon of *Gastrioceras* (*Girtyites*) *zitteli*. This association of goniatites has made it possible to correlate this zone with an horizon in the upper Wushan limestones of the Yangtze gorges at Ichang, in which two rather imperfectly preserved shells of *Anderssonoceras anfuense* have been found. Though much worn, these show the characteristic ventro-lateral and umbilical angulations of the species. This horizon lies about 1100 meters above the base of the limestone series, or about 1000 meters above the top of that portion referable to the Chihsia (Dinantian) horizon, or 400 meters above the *Oldhamina* beds of the gorge limestone (see Section I, Plate V).

Gastrioceras (*Girtyites*) *liui* Grabau is placed in this genus because of the existence of spiral striæ in the outer portion of the shell. These, however, are not always shown, for the spiral portion which

occupies a very definite part of the shell, is frequently not preserved so that only the inner part of the shell is shown. This is probably the part which Frech has referred to the genus *Paraceltites* (Frech IX, 32 (6) p. 190). He describes it as *Paraceltites pseudoopalinus* because of the general resemblance of the shell to *Ammonites* (*Harpoceras*) *opalinus* of the Jura. In Fig. 302 a compressed specimen of this shell is shown in natural size and to this has been added a section of the spiral portion from another individual in the same bed which, however, only shows the inner part incompletely. Nevertheless it is clearly seen that the two parts belong together, for the growth lines can be traced from the smooth or non-spiral part into the spiral part. Nothing is known of the suture, and the species differs moreover from *Girtyites* and *Gastrioceras* in the absence of the ribbing on the inner whorls and in the very pronounced involution. It may be necessary to separate this in the future under a new generic name. Frech obtained his shells from the Ning-Kwo-Hsien district of southern Anhui, which is in the same general region as the other localities from which these shells have been obtained. *Glyphioceras anfuense* (Fig. 301) is placed in the new genus *Anderssonoceras** Grabau, which is characterized by the angulation of the ventro-lateral as well as the inner or umbilical margin of the shells. The suture, however, is typically *Glyphioceran* in type. The genotype *A. anfuense* is characterized by a very gently convex venter with a median ridge, and by the very pronounced elevation of the umbilical angulation, this projecting strongly beyond the upper angulation and producing a deep umbilical depression. When crushed, the form can be recognized by the relative position and spacing of the angulations.

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* In honor of Dr. J. G. Andersson, the noted Swedish geologist and Mining Adviser to the Chinese Government, who has contributed so much to the material in this volume.

In nearly all localities in which *G. zitteli*, *G. liui* or *A. anfuense* have been found, they occur in beds either intimately associated with, or a short distance below, others which carry the *Gigantopteris* flora. In the only locality where this has been specifically identified in association with these goniatites, *i.e.*, in the Taochung mining district of Anhui (Hayasaka IX, 50) the species is *G. dentata* Yabe, the stratigraphically higher of the two species known from China.

The PEICHIEN FORMATION of Kinshan, north-west Hupeh, corresponds to the Hsuanchin coal series and the overlying Paoan shale with *Gastrioceras*, etc. These beds are argillaceous sandstones, somewhat shaley and fossiliferous. The shells of a small *Reticularia lineata* are abundant but generally much crushed. Occasionally they show the fimbriate character of the surface. The most characteristic fossil however, is a species of *Agathiceras* to which the name of *A. kinshanense* Gr. (sp. nov.) has been given. This shell is involute and non-umbilicated and is characterized by spiral lines which cover the entire surface. These spirals are narrow and sharp and separated by wider interspaces. The distance between the crests of 5 spirals is 3, millimeters. The aperture of what must be regarded as the adult, represented in our collection by a fragment, shows a dying-out of the spirals, the outer margin being smooth. In the impression of these spirals there appears a small pit near the outer end of each spiral, suggesting a node. The side of the aperture is prolonged into an auricular appendage, above which there is a second long and narrow blade-like extension about 1.5 millimeters wide at the broadest end, and marked by a median ridge. This blade is not fully preserved but extends at least 15 millimeters beyond the edge of the shell above it, while the ear next below projects about 5 millimeters beyond the same point, having a maximum width of 2 millimeters.

Associated with this goniatite are small specimens of *Carbonicola wangsoweni* Gr., about one-half the size of the shell found in the Huk'ou shale of Fukien (see below). Another characteristic species of these sandy shales is a small *Conularia*, provisionally named *C. simplicosta* Gr. (sp. nov.). It is flat-sided with only a faint impression of the median line, which does not interrupt the transverse costæ. These are smooth, not ornamented, straight and number 28 in 5 millimeters. The shell tapers at the rate of 1.10 millimeters in 10 millimeters, the greatest width of the side observed being 4 millimeters.

The same horizon is represented by the TAOCHUNG FORMATION of Ch'ang-Lung-Shan, in the Tao-Chung mining area of Fan-Ch'ang-Hsien, in Anhui (Locality 703). Here the iron ore underlies the quartzite and is in turn followed by thin sandstones. Some distance above this lie thin yellow-gray mud rocks (No. 5 of section, Fig. 27, p. 220 Tegengren 56), which carry a fauna formerly referred to the Loping horizon but now known to represent the Paoan or *Gastrioceras* zone at the base of the Upper Permian. This bed carries a large species of *Agathiceras* here named *A. tegengreni* Gr. (sp. nov.). The young of this shell is apparently of the same character as the half grown shell of *A. kinshanense*. The spirals of the adult, however, are about 2 millimeters apart on the side and one millimeter on the venter and they are about twice the height and thickness of those of the young shells. In a crushed fragment of a very large shell (from 8 to 9 centimeters in diameter) which is believed to belong to this species, the spirals of the outer whorls are rounded ridges one millimeter in width and separated by concave interspaces 2 millimeters in width. Here again, however, they become very crowded on the venter, being about half the size and half the distance apart. Another fragment which may belong to this species or to a related one, shows a maximum distance from ridge to ridge, in the center, of 5 millimeters,

rapidly decreasing outward to 4 millimeters and finally to 3 millimeters. Between the spiral ridges are broad, shallow, concave interspaces. Transverse wrinkles or convex ribs, 2 millimeters or more in width, cross these spirals, forming with them incipient nodes. These wrinkles are separated by interspaces 2 to 3 millimeters in width, widening outwards.

Associated with these goniatite shells are a few brachiopods among which the following have been identified: *Productus kiangsuensis* Chao, *Marginifera lopingense* Chao, *Chonetes* sp. Hayasaka reports the occurrence of *Gastrioceras* (*Girtyites*) *zitteli* in this region, about 140 meters below the beds with *Gigantopteris dentata*, in what is probably the same formation (see *ante* p. 368). These goniatites, therefore, all serve to indicate the Paoan Formation at the base of the Upper Permian.

In the Chian region of south-west Kiangsi, the *Gastrioceras* horizon is followed disconformably by Rhætic or Lower Jurassic coal-bearing beds, but in the Yangtze valley the goniatite horizon is succeeded by variable thicknesses of thin-bedded, sparingly fossiliferous limestones. In south-east Hupeh (Sect. II, Plate V) this is the Tayeh limestone 500 meters thick, while a similar limestone (uppermost Wushan in the Yangtze gorges) reaches a thickness of 750 meters (Section I). In north-west Kiangsi (Sect. III) where the *G. zitteli* zone has not been differentiated, a thin-bedded limestone series with chert at the base, which overlies the Laohu coal series, is about 400 meters thick, and has been named by T. C. Wang the Peishan limestone. It has furnished *Productus sinensis* Frech, a species also found in the Hsuanchin coal series of south-eastern Anhui (Sect. IV). Besides the brachiopods there are many highly specialized Foraminifera referable to *Schwagerina* and other genera. These have not been studied.

The equivalent of the Tayeh and Peishan limestones is found in the Shipi limestone of south-east Anhui (Sect. IV), which has a thickness of 400 meters or more, and so far has furnished no fossils. In the Nanking hills the same series appears to be represented by the Chinglung limestone which overlies the Lungtan coal series. This has so far furnished only Fusulinoids and Schwagerinoids, which have not yet been studied, and exact correlation is at present not possible. In the east Chekiang, and in the Chian sections of south-western Kiangsi (Sections VI and VII), this limestone is absent either through non-deposition or because of subsequent erosion, Jurassic or Rhætic? continental beds resting upon the earlier marine Permian strata.

Returning now to the southern border of the Permian geosyncline of south China, we must next consider the famous Leipakou coal basin of Hunan which lies about 75 miles due west of the Chian section of south-west Kiangsi. This is the locality from which *Gigantopteris nicotinæfolia* was first obtained, as already discussed on page 388, but it may here be reiterated that the shales which carry this flora lie directly upon the older crystallines, and were therefore deposited along, and outside of the southern border of the geosyncline. Occasional flooding of the low land of this region is indicated by the occurrence of beds with marine fossils, chiefly pelecypods The following species have been described by Frech from these beds: *Pseudomonotis radialis* Waag., *Aviculopecten coxanus* Shum. var. *sinensis* Frech, *Leda præacuta* Waag , *Nucula beyrichi* Schaur., *Pleurophorus subovalis* Waag., *P.* cf. *acuteplicatus* Waag., *Schizodus pinguis* Waag., *S. compressus* Waag., *Astarte ambiensis* Waag., *Allorisma* cf. *subelegans* Meek, *Edmondia* cf. *nebrascensis* Gein., *E. tiesseni* Frech, *Bellerophon* sp. Brachiopods are entirely absent, probably because of the facies of the sediment, which only favored the existence of more or less dwarfed pelecypods. The species which have been specifically determined all occur in the upper Productus limestone

of India and the horizon therefore, probably represents the latest marine Permian of this region.

Beds carrying the *Gigantopteris* flora appear to be widespread over south-eastern Kiangsi, extending to the Fukien border. In western Fukien (Changting section) the Upper Permian appears to be largely represented by non-marine river flood-plain and lacustrine deposits, though, as already noted, a bed filled with an elongated form

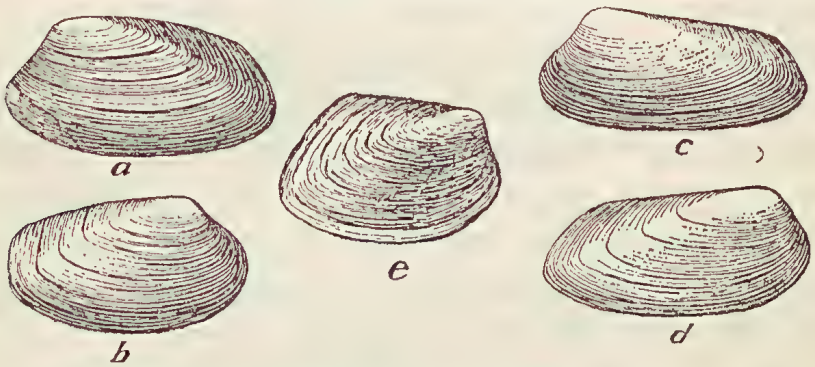

Fig. 303. Fresh-water pelecypods of the Upper Permian (Hukou shale) of Fukien province. *a-b*, *Carbonicola wangsoweni* Grabau; *a*, left and *b*, a smaller right valve more truncated posteriorly than usual (cat. 728, 729); *c-d*, *Anthracomya wardiformis* Grabau; *c*, left, *d*, right valves (cat. 730, 731); *e*. *Anthracomya modiomorphoides* Gr. right valve (cat. 735). All nat. size.

of *Productus cora* var. *fukienensis* Chao, occurs in this region. There is also a limestone full of fusulinoid and schwagerinoid Foraminifera, which probably marks the highest marine Permian of the region, though the exact position of this bed has not been ascertained. A preliminary section made by Mr. S. W. Wang of the Survey, shows the granite of the Changting region to be succeeded by shaley slates 500 meters thick, followed by quartz sandstones also 500 meters in thickness. These in turn are followed by sandstones and later by conglomerates, each 100 meters in thickness. Above the conglomerate, which sometimes forms the cores of eroded anticlines, follows a soft dark to black shale, HUK'OU SHALE, which at certain levels abounds in fresh water pelecypods of the genera *Anthracomya* and

Carbonicola, genera which are typical of the fresh-water Coal Measure shales of Great Britain and other parts of western Europe. The most common form is *Anthracomya wardiformis* Gr (sp. nov.) (Fig. 303 c-d). This has the general form and proportions of *A. wardi* Salt. from the Upper Coal Measures of Great Britain, though being somewhat narrower in the posterior end, a feature unusual in this genus. It is, however, truncated posteriorly as is usual in types of the species of this genus, and has a strongly wrinkled periostracum. *Anthracomya modiomorphoides* Gr. (sp. nov.) (Fig. 303-e) is a rare form, being shorter, with the posterior end high, the umbonal ridge rather strong and the oblique posterior truncation well marked. The beak is near the anterior end (in anterior 5th) and the periostracum is strongly wrinkled. The genus *Carbonicola* is represented by several species, most common among which is *C. wangsoweni* Gr.* (sp. nov.) (Fig. 303 a-b). This has the general character of *C. turgida* (Brown) of the British Coal Measures, but is less inflated and less narrow posteriorly. The posterior end, as is common for this genus, is rounded, though not so pronouncedly as in some other species, and the umbonal ridge is slightly developed. Another species is *Carbonicola ovalis* Gr. (sp. nov.), which is elongate oval with the beak at or near the center and the length slightly less than twice the height. The beaks are not prominent and the ends are rounded, the posterior somewhat more abruptly than the anterior. This species is small, the length ranging from 13 to 14 mm. and the corresponding heights from 7 to 7.5 mm. Another species is short and round and it is provisionally compared with *Carbonicola subrotunda* Brown of the English Coal Measures. At one locality, which represents probably a slightly different horizon, shells of *Estheria fukienensis* Gr. (sp. nov.) abound. These are of about the same size and proportions of *E.*

* Named after Mr. Wang-Sow-Wen, who collected these fossils.

portlocki Jones from the Permian of Great Britain. A typical specimen is 7 mm. long, 4.50 mm. high and has the beak in the anterior third, though this is not pronounced. The hinge-line is straight, a little more than half the length of the shell. The surface is characterized by narrow, sharp concentric ridges, separated by broad concentric interspaces. In the umbonal part there are from six to seven of these ridges to one millimeter while in the lower part there are usually only about four to one millimeter. There is the same variation in the proportional length and width, and in some specimens the beak appears to be nearer to the anterior end, but I do not think that more than one species is represented. There are many fine vertical wrinkles between the concentric ridges, and the lower part is commonly marked by coarser transverse wrinkles due to compression. Associated with this shell are specimens of *Carbonicola wangsoweni* Gr. and *Anthracomya wardiformis* Gr.

As before noted, the *Productus* bed of this region is probably to be regarded as lying within this shale series, marking a temporary widespread inundation of the region by the sea from the Permian geosyncline. As these marine fossils are found in a totally different section from, though in the same general region with, the *Anthracomya* beds, no definite correlation can be attempted. The Huk'ou shales are said to be succeeded by 300 meters of limestone without fossils, which may perhaps be the same formation which elsewhere in this region has furnished the Fusulinæ, etc. If that is the case, this limestone probably corresponds to the Tayeh limestone of the Yangtze section and was formed within the same period of wide transgression of the waters of the geosyncline over its borders at the close of Permian time.

One fact of importance must be noted and that is the association of numerous trunk fragments, branches and leaf-impressions of a new form of *Neocalamites* (*N. fukienensis* Chow) with the pelecypods

Anthracomya and *Carbonicola*, these and the plants not infrequently occurring in the same hand specimen. The *Neocalamites* is related to *N. hoerensis* (Schimper), which was originally placed under *Schizoneura* and described from the Rhætic of Sweden. It is also very close to *Schizoneura carrerei* Zeiller (Zeiller IX-116, p. 137, pls. 36-38) from the so-called Rhætic of Tonking. This suggests a very late Permian age for these strata. It is not believed that they are post-Palæozoic because of the associated pelecypods which have a distinct late Palæozoic aspect. Moreover, plants of the type of *Neocalamites* and referred to the genus *Schizoneura*, have been found not only in the Gondwana flora of India and western China, but also in the late Palæozoic beds of the Kusnezk basin in northern Siberia (see *ante* p. 397). Again, if the Fusulina limestone of the west Fukien region overlies the Huk'ou shale (and there appears to be no other position which it can occupy in the series) the Permian age of the pelecypod shales is indicated. On the whole, they probably represent the continental equivalent of the Fêngtien beds of south-western Kiangsi.

South-West China.

(Yunnan)

An important locality of Permian fossils in western Yunnan is Ta-li-shao, a hamlet about 12 miles N.E. of Yung-chang-fu and 4 miles south-west of the nearest point on the Mekong River. Its location is approximately Long. 99° 22′ E., Lat. 25° 15′ N. (Coggin Brown 8). In this region the older limestones (Ordovician, etc.) are followed by decomposed andesitic and diabasic lavas and tuffs, and near Ta-li-shao by fossiliferous calcareous shales and limestones. From these Loczy had obtained a series of fossils which were, however, incompletely identified specifically. He obtained his fossils from the yellowish-gray micaceous sandstone inter-bedded with compact bands of bituminous limestone, which furnished badly preserved specimens of

Productus (aff. *latirostratus* Howse) and *Spirifer* cf. *alatus* Schloth. (Loczy VII-25 p. 204). Coggin Brown obtained a larger collection of fossils from these beds which were identified by Cowper Reed (45) who gives the following list: ANTHOZOA: *Michelinia yunnanensis* Reed (sp. nov.), *Syringopora?* sp., *Zaphrentis* three species; CRINOIDEA: *Poteriocrinus* cf. *maschatensis* Roman, *P.* sp., *Crinoid* stems 4 types; BRYOZOA: *Fenestella assumpta* Reed (sp. nov.), *F. elusa* Reed (sp. nov.), *Rhombopora?* sp., *Thamnicella orientalis* Reed (sp. nov.), *Acanthoclema?* sp., *Geinitzella* sp.; BRACHIOPODA: *Orthotichia morganiana* (Derby), *Derbya* cf. *grandis* Waag., *Productus semigratiosus* Reed (sp. nov.), *P. tenuistriatus* de Vern., *P.* cf. *cancrini* de Vern., *P.* cf. *cora* d'Orb., *P.* cf. *plano-hemisphærium* Netsch., *P.* (*Pustula*) *pustulatus* Keys., *P.* (*Pustula*) *abichi* Waag., *P.* (*Pustula*) *waageni* Rothpl. var., *P.* sp., *Strophalosia proxima* Reed (sp. nov.), *Chonetes pseudovariolata* Nik. var. nov. *yunnanensis* Reed, *C. molengraaffi* Broili, *C.* cf. *geinitziana* Waag., *C.* aff. *transitionis* Krot., *Athyris* (*Cleiothyridina*) *roissyana* Keys., *A.* cf. *timorensis* Rothpl., *A.* (*Actinoconchus*) sp., *Spirifer fasciger* Keys., *S. fritschi* Schellw. var. nov. *peregrina* Reed, *S. rajah* Dav., *S. schellwieni* Tschern. var., *S.* aff. *carnicus* Schellw., *S.* cf. *tastubensis* Tschern., *S.* cf. *varuna* Dien., *Spirifer* (*Martinia*) cf. *simensis* Tschern., *S.* (*Martinia*) *bellistriatus* Reed (sp. nov.), *S.* (*Martiniopsis*) *talishaoensis* Reed (sp. nov.), *S.* (*Martiniopsis*) cf. *chidruensis* Waag., *S.* (*Martiniopsis*) sp., *Reticularia sublineata* Reed (sp. nov.), *Notothyris?* sp., *Camarophoria* aff. *purdoni* Dav., *Rhynchopora? emerita* Reed (sp. nov.); PELECYPODA: *Aviculopecten hiemalis* Salt. var. nov. *alta* Reed, *A.* cf. *deprati* Mans., *A.* aff. *kokscharovi* de Vern., *Palæolima scabrosa* Reed (sp. nov.), *Modiola yunnanensis* Reed (sp. nov.), *Parallelodon* (*Macrodon*) cf. *multistriatus* Girty, *P.* (*Macrodon*) cf. *tenuistriatus* Meek, *Conocardium* aff. *rouxi* Mans.; GASTROPODA: *Pleurotomaria?* sp., *Bellerophon?* sp. Reed, following Tschernyschew, refers this fauna to the

Permo-Carboniferous, considering it essentially equivalent to the Middle Productus limestone. According to the classification here adopted, this is regarded as Middle Permian and this is in accordance with the faunas of China and Mongolia. The succeeding Permian horizons are represented by continental Red Beds.

So far as we now know, the region between the Salween and Mekong rivers contains only marine Middle Permian (Middle Productus limestone horizon), the later Permian being represented by continental red beds. The Permian beds rest apparently upon the Dinantian with a disconformity between, no representatives of the Taiyuan series, or the higher Carboniferous and early Permian being present. Some of these are, however, found farther east in the Yunnanfu region.

What may eventually prove to be the formations deposited in an invasion of the south Chinese region by waters from the Indian Ocean in early Permian time, are found in the region around Yunnanfu. In the cliffs bordering lake Tang-Tsung, about 20 miles east of Yunnanfu, limestones overlying the Dinantian and Taiyuan series, probably with a disconformity, carry, what Reed - following Deprat - classes as an Upper Carboniferous fauna, though Frech refers these upper Uralian beds of Deprat to the Lower Permian (see ante, p. 297). West of the northern end of the lake, where the road from Tang-Chi crosses these outcrops (abt. Long. 103° E., Lat. 24° 58′ N.), the following species, identified by Reed (45, p. 318) were obtained by Coggin Brown (7, p. 107). FORAMINIFERA: *Fusulina* sp., *Endothyra* sp., *Cribrospira* sp.; PORIFERA: *Renieria* sp., *Haplistion* sp., *Sollaria* cf. *dussaulti* Mans.; ANTHOZOA: *Araeopora ramosa* Waag. & Wentz., *Menophyllum?* sp.; BRACHIOPODA: *Rhipidomella* aff. *pecosi* Marcou, *Spirigerella subtriangularis* Reed (sp. nov.), *Martinia tangchiense* Reed (sp. nov.); GASTROPODA: *Microdoma? parvituberculata* Reed (sp. nov.), *Naticopsis* sp. Fifteen miles farther north at

Yanglin (Long. 103° 7′ E., Lat. 25° 13′ N.), these beds have furnished *Fusulina* sp., *Endothyra* sp. and *Raniera?* sp.

Beds of this Lower Permian (upper Uralian?) series are well developed in the vicinity of Yunnanfu. About 10 miles south-west of Yunnanfu, at Tzu-mên-lu (Long. 102° 36′ E., Lat. 24° 58′ N.) isolated outcrops of hard bluish-gray limestone carry *Neoschwagerina craticulifera* (Schwager) (Fig. 214, p. 296), and *Fusulina* cf. *montipara* Ehrenb. The former is a typical zone fossil of the late Lower Permian (Upper Uralian of Deprat, see table p. 297). A short distance to the south-west, these beds are succeeded by the continental Permian red beds.

The *Neoschwagerina* horizon is again found at Pu-erh-fu on the Black River (Pa-Pien-ho) about 50 miles east of the Mekong (Long. 101° 3′ E., Lat. 23° 5′ N.). Here limestones underlying the Red Beds and apparently resting unconformably on the older Palæozoic, have furnished the following fauna of Foraminifera etc. (Coggin Brown 10, p. 319, Cowper-Reed 45, p. 318): *Endothyra* sp., *Valvulina* sp., *Bigenerina* sp., *Fusulina* sp., *Climacammina?* sp., *Trochammina?* sp., *Neoschwagerina* sp., *Geodites* sp.

North China.

The only representative of the marine Permian formations yet known in northern China is that of the Shansi horizon, already discussed at some length in the preceding chapter. This represents the invasion of north China at the beginning of Permian time, while south and central China were still free from marine waters. The Shansi formation is, so far as we know, not found in southern China, nor are the Loping and later Permian marine horizons found in northern China. The Shansi series represents a distinct invasion of north China from the mid-Asiatic waters through Sinkiang and the Nanshan geosyncline of Kansu. The extent of this invasion was less

than that of the Taiyuan invasion of north China, though the number of known sections is as yet comparatively small. As in the case of the Taiyuan region, the easternmost section for the Shansi series is in the Kaiping basin of eastern Chihli, where the Shansi series contains many coal beds, as already noted, with only a few thin marine members in the lower part. The chief one is the Chaokouchuang formation, which overlies coal bed No. 13, and the total thickness of which is not over half a meter. This clearly shows that the Kaiping region lies near the eastern border of the Shansi basin and that the Chaokouchuang formation represents only a temporary invasion of the coal swamp region by the sea from the west. On the north the horizon of the Shansi series has been discovered by Pères Teilhard de Chardin and Licent, some distance north of Kalgan and south-west of Delonnor, (approximately Lat. 41° 30′ N., Long. 115° E.). About 300 miles south of this, in the Liuhokou coal field of northern Honan, we have reached the southern boundary of the basin, for here the marine members are entirely absent from the Shansi formation, which overlies the Taiyuan series with a thickness of 260 meters. The Taiyuan series itself still has some marine members, as previously noted. In central Shansi, Taiyuanfu region, the Shansi series contains only one marine member, the Tungtayao limestone, 3·2 meters in thickness (see *ante* p. 372). 100 miles north-west of this, however, we meet with a greater development of the Shansi series in north-western Shansi (Pao-Te-Chou region) where the main coal seam is succeeded by the Paotechou limestone 10 meters in thickness, followed by the Tumen formation 14 meters in thickness. Both of these are richly fossiliferous and from them we have obtained our principal representatives of the Shansi fauna of north China. About 400 miles west of Taiyuanfu, in the little known area on the south of the Alashan range in Kansu, and some 50 miles north of Lanchoufu, we meet with a remarkable development of the Shansi series in the Talapai

FORMATION. This is the highest marine formation of the region and, as shown in sections further west, is included in continental beds, which disconformably overlie the Taiyuan series. In the section from Sohanpu to Ta-La-Pai, about 60 kilometers in length, these beds are exposed in very regular anticlines and synclines (Fig. 304). According to Wong and Hsieh, the series in descending order comprises the following members.

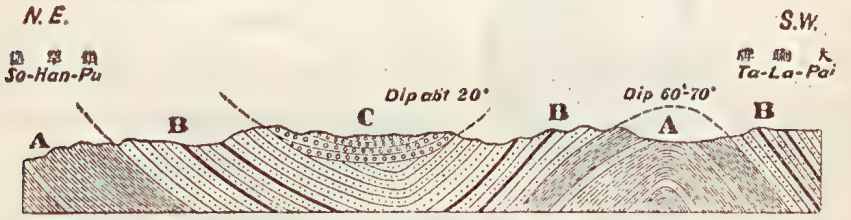

Fig. 304. Section from So-Han-Pu to Ta-La-Pai, Kansu. Length about 60 kilometers (after Wong and Hsieh).
A. *Sohanpu Formation* (Permo-Carb.?).
Red shales with some sandstone beds rich in gypsum. Exposed about..... 300 m.
B. *Talapai Coal Series* (Lower Permian).
White and reddish sandstone, thin layers of fossiliferous limestone and black shale in the coal-bearing strata. Thickness about .....1000 m.
Unconformity
C. Conglomerate (Mesozoic?) 200–300 meters.

C. CONGLOMERATES, probably Mesozoic...200 to 300 meters.

Unconformity

B. TALAPAI FORMATION..... .....1000 meters.
White and reddish sandstones, often coal-bearing with layers of fossiliferous limestone and black shale near the coal (for species see below).

A. SOHANPU FORMATION, exposed..... 600 meters.
Red shales with some sandstone beds rich in gypsum. Base not exposed.

The Talapai series (B) as exposed near Ta-La-Pai, Hung-Shui-Hsien, contains, according to Mr. Yuan,* a series of marine

* The full details of these sections will be published soon by Mr. Yuan.

fossils and plant remains, these often occurring in the same bed. These fossiliferous beds are only about 12 meters thick and occur in the middle of a great sandstone series, being interbedded with coal seams. Small nodules of gray limestone contain numerous young

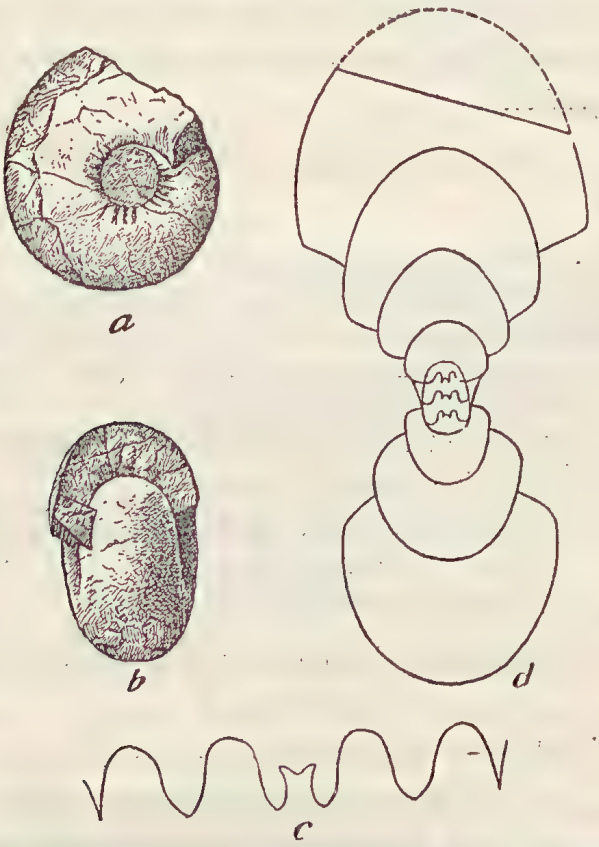

Fig. 305. *Gastrioceras wongi* Grabau; type from Kansu. Young; *a–b*, side and ventral views ×1¼ and *c*, suture enlarged; *d*, section of adult, natural size.

shells of a goniatite here named *Gastrioceras wongi* Grabau sp. nov. (Fig. 305) but only imperfect fragments of the adult shells. With this occurs *Productus hemisphæricus* Kutorga and *Trepospira? kansuensis* Gr. The black shale also contains numerous young specimens of *Gastrioceras wongi* besides a great abundance of pelecypods, among which *Pterinopecten papyraceus* (Sow.), *Posidoniella yuani*

Gr. *P.* cf. *pyriformis* Hind and *Aviculopecten kansuensis* Gr. as well as the brachiopod *Lingula credneri* are the dominant forms.

Summary of the Fauna.

(1) *Gastrioceras wongi* Gr. (sp. nov.) (Fig. 305). This is of the type of *G. carbonarium* with nodes on the inner margin but with an angular sloping suture-wall and flattened sides in the adult. It is also more closely involute than the European species. The suture of the young is like that of *G. carbonarium*, of which this species appears to be a derivative. No spiral striæ are shown on the surface as in *Gastrioceras jossæ* of the Artinskian of Russia, another form to

Fig. 306. *Productus hemisphæricus*, 3 views. After Netschajew.

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which our species is rather closely allied. There are occasional constrictions. The last whorl has the inner sutural angle abrupt and without nodes, which are confined to the young. Occasionally, however, strong distantly-spaced tubercles occur with nodeless spaces of some length between. In the young the nodes extend as ribs to the suture but only a short distance beyond the umbilical angle. Adult shells of this form seem to be very rare but the young are common, having apparently been carried by floatation into these sediments.

(2) *Productus hemisphæricus* Kutorga (Fig. 306). This typical Russian Permian species is represented by a single specimen in our collection, this having been obtained from the limestone nodules.

(3) *Trepospira? kansuensis* Gr. (sp. nov.) This is a low-spired shell with faintly impressed sutures and with numerous fine,

slightly forward-bending riblets below the suture, these dying away outwards, occupying about one-third the width of the shoulder in the young but one-fourth in the adult. The band is wide and situated just above the shoulder angle, being partly covered by the succeeding whorls. The slit is short. Internal moulds ribless. Only 4 specimens of this rather striking species have been obtained.

(4) *Pterinopecten papyraceus* (Sowerby). This characteristic shell of the European Upper Coal Measures is represented abundantly in the black shale of the Talapai formation, the specimens being indistinguishable from the characteristic European forms.

(5) *Posidoniella yuani* Grabau (sp. nov.). This is closely allied to *P. vetusta* Sow. of the Carboniferous limestone of England, Belgium, Russia, etc. but as a rule is of less average size, and the concentric wrinkles are less regular. The specimens are usually compressed and as a result, often show radiating lines or folds which are very irregular, though at first they might be mistaken for radial ornamentations. This shell is very abundant at certain horizons.

(6) *Posidoniella* cf. *pyriformis* Hind. A small smooth species with fine concentric wrinkles appears to be closely allied to *P. pyriformis* of the Carboniferous limestone of England, although it will probably prove to be a distinct species. It is abundant at certain horizons, associated with *Lingula credneri*.

(7) *Aviculopecten kansuensis* Gr. (sp. nov.). This is a rather small species. The left valve is moderately convex, both ear and wing well marked, the latter projecting in an acute angle. The posterior shell-margin is strongly oblique and the hinge is shorter than the width of the shell below. When not flattened, the height is greater than the antero-posterior length. The surface is characterized by sharp, thread-like radiating lines, far apart and with occasional intercalations. These radii are cancellated by sharp, concentric lines

which are equidistant but less pronounced than the radiating lines. The ear and the wing generally have fewer radiating lines but the concentric lines are very pronounced. The right valve has a rather pronounced excavation below the anterior ear and is smooth or finely wrinkled concentrically, but the ear and wing have sharp regular concentric striæ, while radiating striæ are sometimes pronounced on the ear but less so on the wing. In form and general appearance, this shell resembles somewhat *A. losseni* von Kœnen of the Pendleside series of England and the Culm of continental Europe, but it is smaller and has much sharper, more distantly spaced striæ, and more pronounced equidistant concentric lines. This shell is common in the black shale.

(8) *Lingula credneri* Geinitz. This characteristic Permian species of Europe (also found in the Carboniferous of England) appears to be well represented in the Talapai shales. Our shell agrees very closely with the one figured by Davidson on plate 48, fig. 39. The average length of our specimen is 6 millimeters. It is associated with *Posidoniella* cf. *pyriformis* and *P. yuani*.

The revised stratigraphic succession of the marine Permian, as now recognized for central and north China, is as follows in descending order. (See Correlation Table, Pl. VI).

PERMIAN AND DINANTIAN OF CENTRAL AND NORTH CHINA

Superformation—Usually Rhætic coal series

Hiatus and Disconformity

PERMIAN

TAYEH LIMESTONE

PAOAN SHALES (*Gastrioceras* shales)

FÊNGTIEN SERIES (in part equivalent to, or including, Paoan shales and Hsuanchin coal.

HSIAOCHIANG LIMESTONE (*Orthothetes tingi* zone).

Changsing limestone (*Oldhamina* horizon)

Loping formation (*Lyttonia richthofeni* horizon)

Shansi series (North China)

Disconformity

Dinantian

Taiyuan Series (North China)

Chihsia limestone Viséen (Central China); Choniukou limestone (Kansu)

Hiatus and Disconformity

Subformation: Silurian sandstones and shales

Summary of Permian Palæogeography.

(Maps, Plates III and IV).

The details furnished by the sections discussed in the foregoing pages enable us to see with greater clearness than heretofore, the progress of events in the geographic development of China during the closing epochs of Palæozoic time. After the final retreat of the waters at the end of the period in which the Taiyuan strata were deposited, the whole of the Chinese territory appears to have become dry land and remained so during the greater part, if not the whole, of Moscovian and Uralian time. If, as has been stated elsewhere, the lower Productus limestone of the Salt Range represents the early Upper Carboniferous, *i.e.*, Gschellian, it marks a temporary readvance of the sea in the Himalayan geosyncline after a long period of non-deposition, which began with the withdrawal of the waters at the end of Dinantian time. There is at present, no reliable evidence that Moscovian time is represented by marine strata in southern and eastern Asia. None are positively known from the Himalayan geosyncline, from the Chinese basin or from the Mongolian geosyncline. The readvance of the sea in Gschellian time, if it took place, seems to

have been limited to the Himalayan geosyncline but it may also have extended into south-western China and perhaps into Indo-China.

The first invasion of the Permian sea into China seems to have been restricted to north China (Pl. III), where it is indicated by the marine beds intercalated between the continental systems of the Shansi series. These invasions proceeded through the Nanshan geosyncline, as shown by the Kansu sections. The fauna preserved in the Talapai shales has a decided west European aspect, while typical Permian forms of the Russian basin are also present. (See also *ante*, pp. 403-404). This invasion corresponds approximately to the Artinskian period of the Russian Permian, an horizon which so far as known, is wholly unrepresented in the deposits of the central part of the Mongolian geosyncline or in those of south China, though certain forms in the Yunnan succession have been referred to the Lower Permian. If these actually belong to this horizon and if, as appears to be the case, the Lower Permian is absent in the Himalayan geosyncline, the Lower Permian beds of south-west China must be regarded as representing an independent invasion from the Indian Ocean of this period. The Shansi series is, however, independent of it and represents an invasion of the north European waters.

By the close of the Shansi period the sea had permanently withdrawn from the north Chinese basin where continental sedimentation however, continued. These continental beds have already been described on page 371 and it was there shown that they indicate a progressive desiccation of the north China region, until it became a desert basin similar to the Taklamakan basin of present day Sinkiang province.

Meanwhile, at the opening of mid-Permian time, the sea filled the south Chinese basin and the Mongolian geosyncline (Pl. IV), the invasion most probably proceeding from the south and the east, *i.e.*, from the Indo-Pacific province, which was the home of the

Lyttonia fauna. This is clearly shown by the occurrence of this fauna not only in the coastal region of the Asiatic borders of the Pacific, *i.e.*, Japan, the Maritime Provinces of Russia, Indo-China, etc., but also in south-western North America, *i.e.*, the Guadaloupian region of Texas, which was an embayment from the Pacific Ocean of the period.*

It is most probable that this fauna entered the Chinese basin from the south, from Indo-China, spreading northward and eastward in the Tsingling and Loping geosynclines, the latter of which opened to the Pacific in the region of the modern Yangtze mouths (see map Pl. IV). It is of course, possible that a part of the fauna entered the Loping geosyncline direct from the Pacific opening on the east, though the comparative narrowness of that water-way may have made this more difficult. From south China this fauna spread westward in the Himalayan geosyncline where it is represented in the middle Productus limestone. The westernmost extension is seen in the Mediterranean region of southern Europe, especially in the Bellerophon limestones of the Alps and Italy. In the southern Alps the Bellerophon limestone carries an abundant fauna which is clearly of the Indo-Pacific type. Here occur *Richthofenia* aff. *laurenciana* de Kon., *Productus indicus* Waag., *P. abichi* Waag., *Marginifera ovalis* Waag., *Lonsdaleia indica* Waag. & Wentz. etc. (Shellwien and Kosmat 48).

That this fauna was of Indo-Pacific origin can scarcely be doubted, not only because of its wide extent in that region, but also because of the distinctness of the faunas of the other centers of distribution. True, we know practically nothing of the Permian fauna of the Atlantic basin, but there seems little likelyhood that the *Lyttonia* fauna originated in that basin and migrated eastward. If

* See the Palæogeographic map of North America. Grabau, Text Book of Geology, Vol. II, p. 519, Fig. 1456.

that were the case it would be more abundantly represented in the Mediterranean deposits. Moreover, no marine Permian is known from the Iberian peninsula or from north-west Africa and it is not improbable that the Mediterranean basin was closed on the west by land. The presence of red sandstones and plant-bearing beds in that region further suggests such a condition, as does also the fact that the Middle Permian continental beds generally lie unconformably on the older Palæozoic. These conditions extend to Andalusia, while in the Atlas mountains of Morocco a great series of red beds with plant-bearing strata rests discordantly on the Carboniferous or older Palæozoic formations. On the other hand, in the Pyrénées of the Ariège, in southern France, beds with a Lower Permian marine fauna like that of Sicily occur. These are shales 35 meters thick, and rest concordantly on Upper Carboniferous strata supporting in turn a sandstone and a new series of unfossiliferous green shales. The fossils in the calcareous nodules of these beds include ammonoids of the genera *Gastrioceras*, *Daraelites*, *Paraceltites*, etc. and other fossils, but all too poorly preserved for specific identification.

The Middle Permian lies discordantly on the Lower, beginning with polygenetic conglomerates and red sandstones and comprising chiefly marls and red argillites. This series supports concordantly the Upper Permian, which consists of dolomites, limestones and black shales. This section resembles strikingly that found in the southern Alps.

There is no conclusive evidence here that the Mediterranean basin opened to the Atlantic, though such a connection is not wholly excluded. If the land area was continuous on the west, then the Permian of Sicily and the southern Alps must have derived its fauna chiefly from Asiatic waters with, no doubt, some contributions from the Boreal sea on the north.

The Boreal fauna was of quite a different type, as is shown by the remains of this fauna in the Russian deposits and in the Zechstein of north Germany.

It is also probable that the *Lyttonia* fauna entered the Mongolian geosyncline from the Pacific on the east since this fauna is well represented in the deposits at the eastern end of this geosyncline, *i.e.*, in the Vladivostok region (Fredericks, 17.)*. Nevertheless, the waters of this geosyncline were in direct communication with those of the Himalayan geosyncline through the central Asiatic region, as is clearly shown by the abundance of types in common between the deposits of Jisu Honguer and those of the Salt Range, forms which are still unknown in the south Chinese basin but are also found in Spitzbergen (Wiman, 63) and in some of the higher "Carboniferous" beds of Russia.

In Australia too, according to Frech (IX-30), only Lower Carboniferous and Permian marine beds are found. The relationship of the faunas of the latter to those of the Lower Permian of Timor is, however, slight, and they apparently represent a higher horizon. Upper Carboniferous marine index fossils such as *Fusulina*, *Schwagerina*, *Enteletes*, *Meekella*, *Trachydomia* and the *Spirifer mosquensis* series, as well as crinoids and goniatites of that horizon, are wholly absent.

So far then as our present knowledge of the Permian fauna of the northern hemisphere permits us to judge, that fauna may be divided into two groups: the Boreal and the Pacific. The former spread over Europe in early Permian time and also entered the north Chinese region, where it constitutes the Shansi fauna. It was however, apparently excluded from the Himalayan geosyncline, from

* A collection of fossils from these beds near Vladivostok is now in the author's hands, and will be reported on in the near future.

south China and from eastern Mongolia, these regions being dry land at that time. In mid-Permian time, when the Boreal fauna extended into Europe in the Zechstein sea, the Indo-Pacific waters transgressed widely over southern Asia, entering the south Chinese basin and the Himalayan geosyncline and extending westward into the Mediterranean basin which apparently was closed on the west. In these south European regions tectonic disturbances had affected the Lower Permian strata, and the Mid-Permian transgression brought a wholly new fauna into this region, this being primarily due to the extension of the Indo-Pacific waters. The transgression of the Boreal sea, however, permitted a certain admixture of types from that realm, and some of these no doubt also became intermingled with the Indo-Pacific fauna in the Asiatic region. The Boreal fauna was, however, largely restricted to north Europe but it also extended into the Cordilleran geosyncline of western North America while the Pacific waters, with their distinctive faunas, transgressed only over a small area in southwestern America, i.e., into the western Texas region.

After the entrance of the mid-Permian *Lyttonia* fauna into the south Chinese basin, a gradual transgression set in, the waters spreading over the borders of the *Lyttonia* basin, thus permitting a progressive overlap of the successive beds of the Middle and Upper Permian. A temporary halt of this transgressive movement was effected at the end of mid-Permian time, when conditions for the formation of extensive coal swamps became widespread in southern China. This was the period of the formation of the main or Upper Permian coal of south China (Tanshan, Laohu, Lungtan and perhaps the Leipakou coals). It was followed by a readvance of the sea with a wide distribution of the Goniatites *Gastrioceras* (*Girtyites*) *zitteli*, *G. liui*, and *Anderssonoceras anfuense* as well as species of *Agathiceras*. Whether these are also of Pacific origin or whether they are modified Boreal types cannot at the present time be determined.

That they spread into the Mediterranean basin as well, is shown by the occurrence of some of them in Sicily, the southern Alps and the Pyrénées. Finally the Permian sea of south China became again the site of extensive limestone deposits as is shown by the great series of limestones which form the Upper Permian of the Yangtze valley (Upper Wushan, Tayeh, etc. limestones of the sections). These limestones are clastic rocks formed by lime-mud and sand, and not directly derived from organisms, but probably from the erosion of older limestones. These older supplying rocks may have been the Ordovician, Cambrian and Sinian limestones of the old-land of central China, but at present we can only assume this as a working hypothesis.

Permian time closed in China, as everywhere else in the known world, with a complete withdrawal of the sea and the widespread development of continental conditions, with frequently accompanying aridity of climate. Not only did the sea withdraw from the continental basins but from the continental shelves of the oceans as well, for this appears to have been the chief cause of the almost world-wide extinction of the shallow-water fauna of the Palæozoic. After a long, unrecorded interval, the survivors returned to the shallow waters of the land, but in modified forms, constituting the Triassic fauna of the early Mesozoic era of the world's history. This problem will be more fully discussed in chapter X, and we may here say farewell to the Palæozoic world of life, which passed from the stage at the end of Permian time, doomed to extinction, except for a few favored types which, through the development of peculiar modifications of structure were able to survive the great catastrophe, and, in the solitude of retreat to the parent oceans, await the period of resurrection to renewed activity, and the opportunity to repopulate a desert world.

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ALPHABETICAL LIST OF CHINESE GEOLOGICAL FORMATIONS (PALÆOZOIC AND OLDER) WITH CHINESE CHARACTERS.

ORIGINAL NAME (and Province)	REVISED FORM	CHINESE CHARACTERS*	AGE	PAGE
Aochêng (Kiangsi)	Aochêng	敖城 (江西)	Permian	361
Changchiakou (Shansi)	Changchiakou	張家溝 (山西)	Dinant. (Taiyuan)	255
Ch'anghia (Shantung)	Changhia	張夏 (山東)	Cambrian	34
Changshan (Chihli)	Changshan	長山 (直隸)	Cambrian	427
Changhsing (Chekiang)	Changsing	長興 (浙江)	Permian	366
Chaokouchuang (Chihli)	Chaokouchuang	趙各庄 (直隸)	Permian	379
Chaotien (Szechuan)	Chaotien	趙店 (四川)	Silurian	132
Chatchong (Yunnan)	Chatchong	(雲南)	Carboniferous	243
Ch'aumitien (Shantung)	Chaumitien	炒米店 (山東)	Cambrian	36
Chaupishan (Shensi)	Chaupi	(陝西)	Devonian	131
Chienshui (Szechuan)	Chienshui	涇水 (四川)	Silurian	132
Chientaokou (Shansi)	Chientaokou	澗道溝 (山西)	Dinant. (Taiyuan)	255
Chishiashan (Kiangsu)	Chihsia	棲霞山 (江蘇)	Dinantian	250
Chikando (Fêngtien)	Chikando	(奉天)	Permian	392
Chinglungshan (Kiangsu)	Chinglung	青龍山 (江蘇)	Permian	364
Chitsun (Chihli)	Chitsun	濟村 (直隸)	Dinant. (Taiyuan)	459
Choniukou (Kansu)	Choniukou	臭牛溝 (甘肅)	Dinantian	447

* Supplied by Dr. W. H. Wong and Mr. Y. C. Sun.

ORIGINAL NAME (and Province)	REVISED FORM	CHINESE CHARACTERS	AGE	PAGE
Choueitang (Yunnan)	Choueitang	水塘 (雲南)	Carboniferous?	292
Choutang (Anhui)	Choutang	竹塘 (安徽)	Permian	469
Chuanshan (Kiangsu)	Chuanshan	船山 (江蘇)	Permian	365
Eulkai (Yunnan)	Eurlkai	兒開 (雲南)	Carboniferous	243
Feilaifông (Chekiang)	Feilaifông	飛來峯 (浙江)	Permian	476
Fêngshan (Chihli)	Fêngshan	鳳山 (直隸)	Cambrian	36
Fêngt'ien (Kiangsi)	Fêngtien	楓田 (江西)	Permian	361
Fuchihkou (Hupei)	Fuchih	富池口 (湖北)	Silurian	438
Fuching (Chihli)	Fuching	復青 (直隸)	Dinant. (Taiyuan)	457
Fuchou (Fêngtien)	Fuchou	復州 (奉天)	Cambrian	35
Hanchung (Shensi)	Hanchung	漢中 (陝西)	Devonian	193
Heijo (Korea)	Heijo	(朝鮮)	Permian	387
Hoakeuou (Yunnan)	Hoakeuou	(雲南)	Dinantian	243
Hoangtien (Yunnan)	Hoangtien	(雲南)	Dinantian	243
Honkeiko (Fêngtien)	Honkeiko	(奉天)	Permian	387
Houkoutsun (Chihli)	Houkout	後溝村 (直隸)	Dinant. (Taiyuan)	459
Hsiamaling (Chihli)	Hsiama	下馬嶺 (直隸)	Sinian	15
Hsiaochiangpien (Kiangsi)	Hsiaochiang	小江邊 (江西)	Permian	361
Hsiaoching (Chihli)	Hsiaoching	小青 (直隸)	Dinant. (Taiyuan)	457
Hsiehtao (Shansi)	Hsiehtao	佘道 (山西)	Dinant. (Taiyuan)	255
Hsuanchin (Anhui)	Hsuanchin	宣涇 (安徽)	Permian	476

ORIGINAL NAME (and Province)	REVISED FORM	CHINESE CHARACTERS	AGE	PAGE
Huanglienpo (Szechuan)	Huanglienpo	黄梁坡 (四川)	Devonian	188
Huangling (Hupei)	Huangling	黄陵 (湖北)	Archæan	20
Huangpayi (Shensi)	Huangpayi	(陕西)	Silurian	131
Huk'ou (Kiangsi)	Hukou	湖口 (江西)	Permian	485
Hungshan (Shantung)	Hungshan	聲山 (山東)	Permian	256
Huto (Shansi)	Huto	滹沱(河)(山西)	Sinian	17
Ichang (Hupei)	Ichang	宜昌 (湖北)	Ordovician	434
Jido (Fêngtien)	Jido	寺洞 (奉天)	Permian	392
Jisu Honguer (Mongolia)	Jisuhonguer	(蒙古)	Permian	340
Kaochiapien (Kiangsu)	Kaochiapien	高家邊 (江蘇)	Silurian	436
Kaolishan (Shantung)	Kaoli	高里山 (山東)	Cambrian	427
Kiautchangpa (Szechuan)	Kiautchangpa	高昌壩 (四川)	Ordovician	131
Kinshan (Hupei)	Kinshan	京山 (湖北)	Ordovician	475
Kisingling (Szechuan)	Kisingling	鷄心嶺 (四川)	Ordovician	91
Koofêngchen (Anhui)	Koofêng	孤峰 (安徽)	Permian	476
Kuahsinshan (Yunnan)	Kuahsin	誇興 (雲南)	Devonian	192
Kuantikou (Shansi)	Kuanti	關店 (山西)	Dinant. (Taiyuan)	255
Kushan (Shantung)	Kushan	箇山 (山東)	Cambrian	35
Kusnezk (Siberia)	Kusnezk	(西比利亞)	Permian	394
Kütsing (Yunnan)	Kütsing	曲靖 (雲南)	Devonian	191
Laohoshan (Chekiang)	Laoho	老和山 (浙江)	Permian	457

ORIGINAL NAME (and Province)	REVISED FORM	CHINESE CHARACTERS	AGE	PAGE
Laohushan (Anhui)	Laohu	老虎山 (安徽)	Permian	503
Laowatong (Yunnan)	Laowatong	老瓦洞 (雲南)	Carboniferous	243
Leipakou (Hunan)	Leipakou	耒垻口 (湖南)	Permian	360
Liangchiashan (Chihli)	Liangchia	亮甲山 (直隸)	Ordovician	67
Loatien (Yunnan)	Loatien	老店 (雲南)	Carboniferous	292
Loping (Kiangsi)	Loping	樂平 (江西)	Permian	363
Lungma (Hupei)	Lungma	龍馬 (湖北)	Silurian	437
Lungtan (Kiangsu)	Lungtan	龍潭 (江蘇)	Permian	365
Lunshan (Kiangsu)	Lunshan	崙山 (江蘇)	Ordovician	96
Machiakou (Chihli)	Machiakou	馬家溝 (直隸)	Ordovician	67
Mant'o (Shantung)	Manto	饅頭(山)(山東)	Cambrian	33
Maoerhkou (Shansi)	Maoerh	毛兒溝 (山西)	Dinant. (Taiyuan)	255
Miaokaoshan (Yunnan)	Miaokao	妙高山 (雲南)	Silurian	126
Miaokou (Shansi)	Miaokou	廟口 (山西)	Dinant. (Taiyuan)	255
Mientien (Yunnan)	Mientien	麪店 (雲南)	Silurian	126
Möngshan (Kiangsi)	Mingshan	鳴山 (江西)	Algonkian?	362
Nankou (Chihli)	Nankou	南口 (直隸)	Sinian	15
Nanshan (Kansu)	Nanshan	南山 (甘肅)	Algonkian?	447
Nantai (Shansi)	Nantai	南台 (山西)	Algonkian	12
Nant'ou (Hupei)	Nantou	南沱 (湖北)	Sinian	19
Nanyaokou (Shansi)	Nanyao	南窰溝 (山西)	Dinant. (Taiyuan)	255

ORIGINAL NAME (and Province)	REVISED FORM	CHINESE CHARACTERS	AGE	PAGE
Neichiashan (Hupei)	Neichia	艾家山 (湖北)	Ordovician	93
Pagoda	Pagoda	寶塔	Ordovician	435
Paloukou (Shansi)	Palou	扒樓溝 (山西)	Dinant. (Taiyuan)	255
Pankou (Shansi)	Pankou	畔溝 (山西)	Dinant. (Taiyuan)	255
Paoan (Hupei)	Paoan	保安 (湖北)	Permian	478
Paotechou (Shansi)	Paotechou	保德州 (山西)	Permian	377
Peichien (Hupei)	Peichien	北澗 (湖北)	Permian	481
Peiching (Chihli)	Peiching	北井 (直隸)	Dinant. (Taiyuan)	460
Peilintze (Chihli)	Peilintze	北林子 (直隸)	Ordovician	67
Peitoutze (Chihli)	Peitoutze	白道子 (直隸)	Dinant. (Taiyuan)	379
Peishan (Anhui)	Peishan	北山 (安徽)	Permian	483
Pingliang (Kansu)	Pingliang	平涼 (甘肅)	Ordovician	430
Pingpa (Hupei)	Pingpa	平壩 (湖北)	Silurian	Pl. VI
Poshan (Shantung)	Poshan	博山 (山東)	Dinant. (Taiyuan)	256
Poshi (Yunnan)	Poshi	婆兮 (雲南)	Devonian	189
Pupiao (Yunnan)	Pupiao	蒲縹 (雲南)	Ordovician	86
Sair Usu (Mongolia)	Sairusu	(蒙古)	Dinantian	434
Shakuotun (Fêngtien)	Shakuotun	沙鍋屯 (奉天)	Cambrian	427
Shangchiaoshan (Kiangsi)	Shangchiao	上樵山 (江西)	Sinian?	Pl. VI
Shanching (Chihli)	Shanching	山青 (直隸)	Dinant. (Taiyuan)	457
Shansi (Shansi)	Shansi	山西 (山西)	Permian	372

ORIGINAL NAME (and Province)	REVISED FORM	CHINESE CHARACTERS	AGE	PAGE
Shichienfeng (Shansi)	Shichienfêng	石千峯 (山西)	Permian	371
Shihhotze (Shansi)	Shihhotze	石盒子 (山西)	Permian	372
Shihchiwakou (Shansi)	Shihchiwa	石齊凹溝 (山西)	Dinant. (Taiyuan)	255
Shihmenchai (Chihli)	Shihmenchai	石門寨 (直隸)	Ordovician	67
Shihtien (Yunnan)	Shihtien	施甸 (雲南)	Ordovician	87
Shipai (Hupei)	Shipai	石牌 (湖北)	Cambrian	426
Shipishan (Anhui)	Shipi	石壁山 (安徽)	Permian	484
Shitsui (Shansi)	Shitsui	石嘴 (山西)	Algonkian	12
Sitai (Shansi)	Sitai	西台 (山西)	Algonkian	12
Sinian (China)	Sinian	震旦	Sinian	14
Sintan (Hupei)	Sintan	新灘 (湖北)	Silurian	298
Sohanpu (Kansu)	Sohanpu	鎖罕堡 (甘肅)	Permian	493
Taching (Chihli)	Taching	大青 (直隸)	Dinant. (Taiyuan)	457
Tafan (Hupei)	Tafan	大阪 (湖北)	Ordovician	438
Tahiti (Yunnan)	Tahiti	(雲南)	Devonian	193
Taishan (Shantung)	Taishan	泰山 (山東)	Archæan	10
Taiso (Fêngtien)	Taiso		Permian	389
Taiyuan (Shansi)	Taiyuan	太原 (山西)	Dinantian	237,253
Talapai (Kansu)	Talapai	大喇牌 (甘肅)	Permian	493
Tangshan (Chihli)	Tangshan	唐山 (直隸)	Dinant. (Taiyuan)	256
Tanshanwan (Hupei)	Tanshan	炭山 (湖北)	Permian	503

ORIGINAL NAME (and Province)	REVISED FORM	CHINESE CHARACTERS	AGE	PAGE
T'aoch'ung (Anhui)	Taochung	桃冲 (安徽)	Permian	482
Tayeh (Hupei)	Tayeh	大冶 (湖北)	Permian	483
Tiensenkouang (Yunnan)	Tiensenkouang	天勝關 (雲南)	Dinantian	243
Tongying (Hupei)	Tongying	燈影 (湖北)	Sinian	422
Tonshant'ou (Anhui)	Tonshantou	銅山頭 (安徽)	Sinian	422
Toumounyi (Yunnan)	Toumounyi	(雲南)	Dinantian	243
T'outsun (Shansi)	Toutsun	竇村 (山西)	Sinian	17
Tsinglingian (Shensi)	Tsinglingian	秦嶺 (陝西)	Devonian	193
Tsoshan (Kiangsi)	Tsoshan	鑿山 (江西)	Perm. & Dinant.	446
T'umen (Shansi)	Tumen	土門 (山西)	Permian	378
T'ungkwanshan (Anhui)	Tungkwan	銅官山 (安徽)	Silurian	444
Tungshan (Yunnan)	Tungshan	東山 (雲南)	Devonian	192
Tungtayao (Shansi)	Tungtayao	東大窯 (山西)	Permian	372
Tungyü (Shansi)	Tungyü	東嶋 (山西)	Sinian	17
Tzuifêngshan (Yunnan)	Tzuifêng	翠峯山 (雲南)	Devonian	187
Weining (Kweichow)	Weining	威寧 (貴州)	Dinantian	246
Wushan (Szechuan)	Wushan	巫山 (四川)	Dinant.-Perm.	251
Wushihmên (Kiangsi)	Wushihmên	烏石門 (江西)	Ord.-Camb.	434
Wutaian (Wutai) (Shansi)	Wutaian (Wutai)	五台 (山西)	Algonkian	11
Wutungshan (Kiangsu)	Wutung	烏桐山 (江蘇)	Silurian	365
Yaishanhsia (Kiangsi)	Yaishan	崖山下 (江西)	Silurian	439

ORIGINAL NAME (and Province)	REVISED FORM	CHINESE CHARACTERS	AGE	PAGE
Yangfoukou (Kansu)	Yangfou	陽阜溝 (甘肅)	Dinant. (Taiyuan)	255
Yangsing (Hupei)	Yangsing	陽新 (湖北)	Perm.-Dinant.	446
Yehching (Chihli)	Yehching	野青 (直隸)	Dinant. (Taiyuan)	458
Yehli (Chihli)	Yehli	冶里 (直隸)	Ordovician	67
Yehshanchung (Anhui)	Yehshan	葉山冲 (安徽)	Perm.-Dinant.	446
Yentai (Fêngtien)	Yentai	烟台 (奉天)	Permian	387
Yenwa (Kiangsu)	Yenwa	硯瓦 (江蘇)	Permian	Pl. VI
Yunghsin (Kiangsi)	Yunghsin	永新 (江西)	Sinian?	361
Yungning (Fêngtien)	Yungning	永寧 (奉天)	Sinian	15
Yunnannian (Yunnan)	Yunnannian	雲南 (雲南)	Devonian	188

ERRATA

Page 9, line 22 from top, for ahem read: them.

Page 13, line 12 from top, for tilver read: silver.

Page 26, line 9 from top, for latter read: later.

Page 65, line 7 from top, for know read: known.

Page 66. line 19 from top, for Honan read: Anhui.

Page 67, line 3 from top, for Kiangsi read: Kiangsu.

Page 70, line 22 from top, for delomitic read: dolomitic.

Page 84, line 8 from top, for west read: east.

Page 87, line 13 from top, for bua read: but.

Page 92, line 4 from top, and line 6 from bottom, for *Orthoceras chinensis* read: *Orthoceras chinense*.

Page 93, under Fig. 64,—same correction.

Page 94, under figure 69, for Erech read: Frech.

Page 102, No. 39, for 1902 read: 1920.

Page 107, line 12 from top, for as well a read: as well as.

Page 126, line 12 from top, for *Modiomorpha* read: *Modiolopsis;* line 13 - see correction in appendix.

Page 127, line 21 from top, for Niagaran read: Monroan (see p. 435).

Page 135, line 20 from top. *S. bourgeoisi* - see correction on p. 435.

Page 143, line 6 from top, for *Gypidula præcursor* read: *Gypidula prognostica*.

Page 144, line 16 from top, for sae read: sea.

Page 157, line 2 from top, for bryzoa read; bryozoa; line 16 from top, for Tienshan read: Tianshan.

Page 160, line 4 from top, for terrestial read: terrestrial.

Page 179, line 12 from top, for *Atryppa* read: *Atrypa*.

Page 181, line 11 from top, for *amaliusi* read: *omaliusi*.

Page 186, Section, for Frssnian read: Frasnian.

Page 223, line 2, line 3, and line 9 from top, for Tauros read: Taurus, for Anti-Tauros read: anti-Taurus.

Page 232, line 18 from top, for Chalytau read: Chalyktau.

Page 235, line 8 from bottom, for p. 229 read: p. 224.

Page 251, line 7 from top, for (Wutai?) - read: (Wushan?) - 5 lines from bottom for Wutai read: Wushan.

Page 254, Section VII, for Huangshan Series, read: Hungshan Series.

Page 284, bottom line, for *P. sinensis* read: *P. simensis*.

Page 288, line 1, for Agglomeratic states read: Agglomeratic slates.

Page 314, Reference No. 64, for Schenck read: Schenk.

Page 331, lines 23 and 26 from top, for Shihhotze read: Shihhotse.

Page 335, under cut, for Fig. 334 read: Fig. 234.

Page 336, line 2 from top, for Fig. 334, read: Fig. 234.

Page 339, under cut, for Fig. 335 read: Fig. 235.

Page 340, line 11 from top, for 333 read: 235.

Page 359, line 3 from bottom, for These two, read: These too.

Page 360, line 3 from top, for Sandai Bay read: Sendai Bay.

Page 364, line 2 from bottom, for Chinglingshan read: Chinglungshan, for Chingling read: Chinglung.

Page 366, lines 1 and 10 from top, for limestone of (in) the Lungtan coal series read: limestones below the Lungtan coal series; line 21 from top, for Fauna of Lungtan Coal Series read: Fauna below Lungtan Coal Series.

Page 367, line 14 from top, for (Fig. 257a) read: (Fig. 261).

Page 368, line 23 from top, for (Fig. 257a) read: (Fig. 261)- In legend of Fig. 256, for Chiglingshan read: Chinglungshan.

Page 369, bottom line, for Tangshanwan read: Tanshanwan.

Page 370, line 2 from bottom, for Seminow read: Semenow.

Page 371, line 15 from top, for Seminow read: Semenow.

Page 373, line 3 from top, for (Fig. 262) read: (Fig. 263).

Page 378, top line, for *Remeleoceras subquadrangularis* read: *Remeleoceras subquadrangulare*.

Page 379, under Fig. 270, for Peioutze, read: Peitoutze.

Page 384, line 5 from bottom, for volue read: value.

Page 385, line 12 from top, for Antung read: Autun.

Page 392, line 6 from bottom, for tyye read: type.

Page 394, line 18 from top, for Zalessky (71) read: Zalessky (108).
line 27 from top, Tangnouola mountain, also written Tannuola mountain.

Page 399, line 4 from top, for Taunu Ola read: Tannu Ola or Tannu-ola.

Page 419, top line, for Vol. XXL read: Vol. XXI.

Page 435, line 8 from top, for *Orthoceras chinensis* read: *Orthoceras chinense*.

Page 436, line 15 from top, for *Phacops* cf. *chinensis* read: *Phacops* cf. *shanensis*.

Page 438, line 15 from top, for *Orthoceras chinensis* read: *Orthoceras chinense*.

Page 444, line 21 from top, for Tongkwan read: Tungkwan.

Page 450, line 7 from top, for Makon read: Mekong.

Page 454, line 10 from top, for col. G. read: col. K.

Page 475, line 5 from top, for *subcostata* read: *subcostatus*.

EXPLANATION OF PLATES *

PLATE I. Map of China, showing the approximate distribution of land and water (black) in Viséen time. The Chinese basin communicated with the waters which covered central Asia and Europe, by the Himalayan geosyncline on the south and the Nanshan geosyncline on the north - but were probably not open to the Indian Ocean on the south. The Himalayan geosyncline is represented as too broad, the region at Lucknow and Delhi probably being a part of the Old-Land. Typical Viséen is found in the Spiti region but is still unknown from regions farther east. In Yunnan, at Ta-Shi-Wo, Siyang and Kütsing, and at Weining in Kweichow, Viséen is well developed. That of the latter region has much in common with the Choniukou region of Kansu in the Nanshan geosyncline, both being characterized by *Productus giganteus* and its varieties. These forms are again abundant in western Sinkiang, Yulduz, Utch-Turfan and Kashgar region, and in the Tianshan, and regions farther west. In the Mongolian geosyncline Viséen faunas are known from Sair Usu and Gasimursk. The waters of the Tsingling geosyncline extend north-east to the region of the present Yangtze mouths. In this inland sea the Chihsia limestone was formed, characterized chiefly by corals and by *Fusulinella gigas*. The mountain ranges shown on the map are those of the present day, given for purposes of orientation. They are of much younger origin.

PLATE II. Map of China, showing the extent of the marine invasion in Taiyuan time. This was the last invasion in early Carboniferous time, the region then becoming dry land and remaining so until the beginning of Permian time. The best known basin is that of north China, and the most complete sections are found in the vicinity of Taiyuanfu. The localities of the principal sections in the north Chinese basin and its

* On Plates I–IV, the position of Chitichun Pk. is misplaced. It should be in Lat. 30° 41′ N., Long. 80° 21′ E., immediately south-east of Shalshal Pk. which is approximately in Lat. 30° 50′ N., Long. 80° 9′ E.

extension in the Nanshan geosyncline are indicated on the map. None of these however show continuous marine series, but rather a succession of marine intercalations between continental beds, which are usually coal-bearing. This indicates that the basins suffered a succession of marine invasions, with long intervals of continental conditions. The Taiyuan fauna as such, is, however, unknown in the central Asiatic deposits and hence we cannot regard the invasions as proceeding from that region. At present, it appears that the Taiyuan fauna arose in the south-west Chinese basin (Yunnan, Kweichow, etc.) by modification of residual Viséen types, and that migrants from this new provincial fauna successively occupied the north Chinese basin whenever that was flooded.

Plate III. Map of China showing the Shansi invasion of the sea in Lower Permian time. The easternmost section in which these beds have been found is at Chao-Kou-Chuang, while the most extensive development is found at Paotechou. Other sections are seen in the Nanshan geosyncline of Kansu. In Lincheng and in the Shantung localities the Shansi series contains no marine beds and near Taiyuanfu it has only one. The fauna contains elements of the Russian Artinskian and the west European late Carboniferous. It is known from the Tarbagatai and Monrack mountain regions of Siberia, and is probably represented in the western Tianshan and regions farther west. The fauna is unknown from central and south China, where Middle Permian beds represent the lowest Permian horizon. The only exception to this appears to be in the Yunnan and Tonking regions where Lower Permian is found to rest disconformably on the Taiyuan or older rocks. This, however, carries a distinctive fauna and may represent an early invasion of the Indian Ocean waters. These beds have also been classed as Uralian by Deprat.

Plate IV. Map of China showing the extent of the marine waters in Middle Permian time, during the period of the *Lyttonia* fauna. In the south Chinese basin this is represented by the Loping fauna which is widely distributed. The fauna is believed to be primarily of Indo-Pacific origin, spreading west through the Himalayan geosyncline (Middle

Productus limestone) and across Mongolia in the Mongolian geosyncline. It has been obtained from the Vladivostok region, from Jisu Honguer and from the region of the Khirgiz Steppes, western Sinkiang, Ferghana, and farther west. In north-west China it occurs in the Semenow and S. Kokonor ranges of the Nanshan chain. In north China this horizon is represented by continental beds. Marine conditions continued in central and south China to near the close of Permian time.

PLATE V. Characteristic Sections of the Palæozoic Formations of South China. These sections are the result of recent field studies by the geologists of the Survey, their interpretation being based on the study of the fossils. The location of all but Sect. VII are shown on the small map, the section not indicated, being off the map and lying 370 miles south-east of Sect. VI, in south-western Kiangsi. In the Yangtze valley (Sections I-V) the Lower Palæozoic is terminated by Silurian shales or sandstones (Wutung), and these beds are disconformably succeeded by the Chihsia limestone of Viséen age. This limestone is in turn succeeded disconformably by different members of the Middle Permian, and these by later marine Permian beds. A coal horizon occurs in most of these sections near the top of the Middle Permian. In the N.E. Chekiang section (VI) and the S.W. Kiangsi section (VII) the Lower Carboniferous (Viséen) is unrepresented, Middle Permian strata resting disconformably (or sometimes unconformably) on Upper Ordovician or on older beds. In both sections a non-marine coal-bearing series (Laoho in Chekiang, Aochêng in S.W. Kiangsi) underlies the marine Middle Permian (Feilaifong-Hsiaochiang) series which begins in both sections with the horizon of *Orthothetes tingi*. The sections are all drawn to the same scale, which is indicated near Section II.

PLATE VI. Correlation table of the Palæozoic formations of China. In this table an attempt has been made to indicate what is known of the Palæozoic horizons of China. The Yangtze valley sections, columns A-F, Column H of the central region and K and L of the south-east border region are localized sections, based on recent detailed study by the Survey

geologists. The Sections in columns G and I are incompletely known, and further study may reveal the presence of other formations corresponding to those of the better known sections. Columns M-P are generalized, covering large areas in south China, north China and Mongolia respectively, and representing combinations of sections often from widely separated localities. Sections I-VII refer to the sections on Plate V. Horizontal lining indicates absence of the respective horizons. Vertical lining indicates horizons unknown because not exposed. Diagonal lining indicates continental formations. Unless otherwise stated the rocks are limestones.

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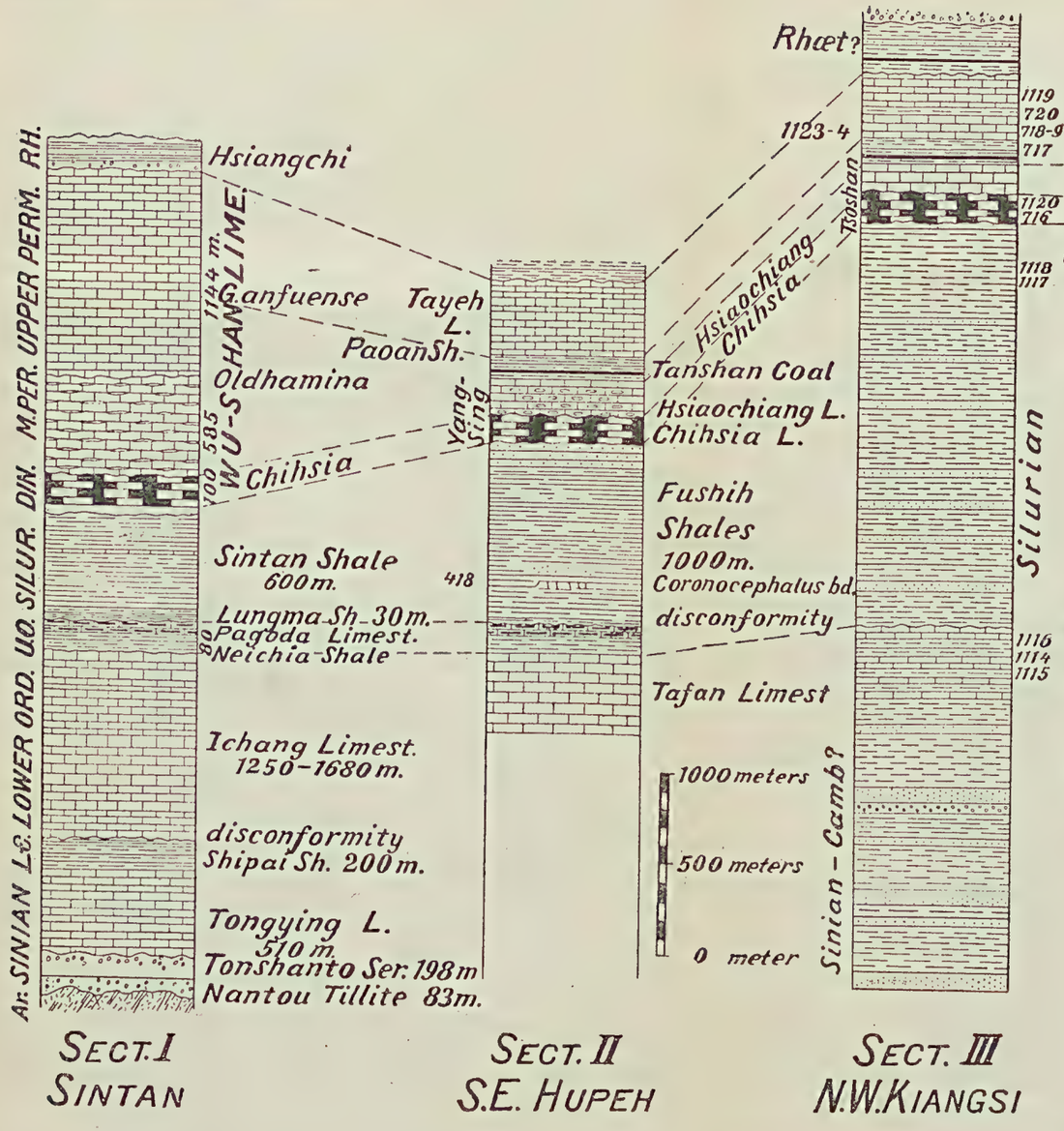

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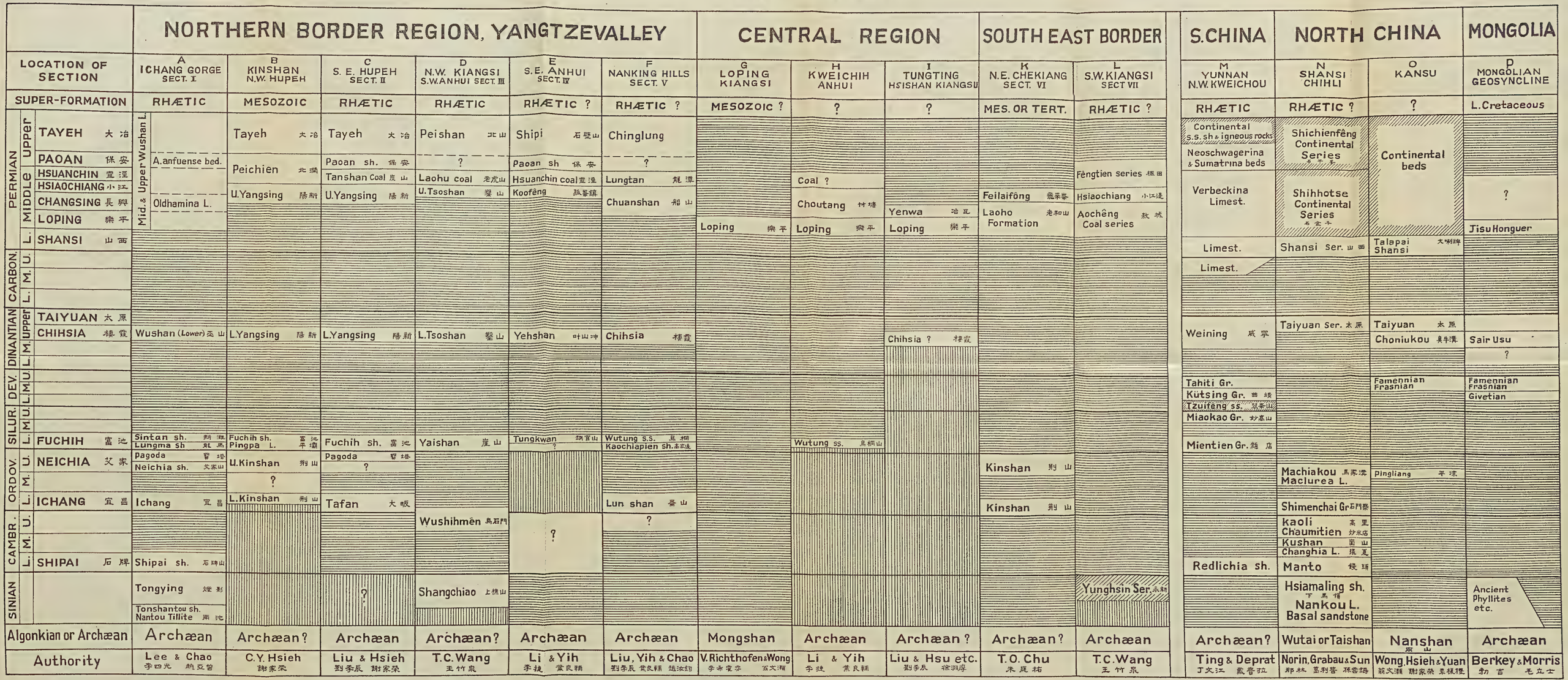

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